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Apmācību semināru būvspeciālistiem un projektētājiem organizēšana

ID Nr. EM 2022/53

Rīga, 2022

Ekonomikas ministrija

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Training seminar / Apmācību seminārs

Construction of Deep Foundation and Excavations in Densely Build Environment

Dziļo pamatu izbūve un ekskavācija blīvas apbūves apstākļos

November 3, 2022, Riga

Prof. M.Topolnicki, Cl.Kummerer, D.Dymek, Gr.Sołtys (Keller Holding)

Semināra norisi nodrošina apvienība SIA “CLEANTECH HUB & CARMELLE” līguma 2022/53 ietvaros

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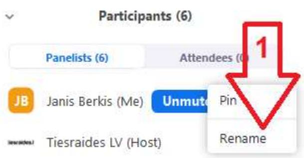
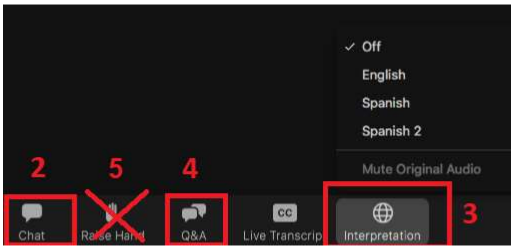
Instructions to participants

1. Write your full name (Vārds, Uzvārds) in participants list
2. Register your name using chat (Vārds, Uzvārds)
3. Interpretation available in Latvian
4. For questions use the Q&A functionality
5. Do not use the reactions or raise hand





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Agenda

09:00 – 10:00	Registration
10:00 – 11:30	Deep foundations and excavation control in dense city environments – challenges and possibilities (by Prof. M.Topolnicki, MSc. CE. D.Dymek, PhD. CE. Gr.Sołtys) • Different systems of retaining walls (secant piles, d-walls, soilmix, nails) • Stability control methods (anchors, struts, decks) • Sealing of deep excavations below groundwater level • Design principles and geotechnical data needed • Case studies of advanced design using FE 3D • Lessons learned from challenging applications
11:30 – 12:00	Coffee break
12:00 – 13:30	Underpinning of buildings and compensation grouting (by Prof. M.Topolnicki, PhD, Cl. Kummerer, PhD) • Principles of jet and compensation grouting • Creating space below existing buildings • Protecting deep foundations • Underpinning of historical buildings • Monitoring of settlements and deformations • Case studies of advanced application • Lessons learned from challenging projects
13:30 – 14:30	Lunch break
14:30 – 15:30	The use of ground improvement for heavily loaded objects by Prof. M. Topolnicki, PhD) • Principles of selected GI methods (vibrocompaction, stone columns, dynamic compaction, wet deep and mass mixing, rigid inclusions) • Design practice and execution • Case studies illustrating the use of GI as an alternative to conventional piling • Benefits from GI applications and reduced CO_2 emission • Lessons learned from challenging projects
15:30 – 16:00	Question and answer session

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Agenda / 10:00 - 11:30

Deep foundations and excavation control in dense city environments – challenges and possibilities (by Prof. Michał Topolnicki, MSc. CE. Daniel Dymek, PhD. CE. Grzegorz Sołtys)

- Different systems of retaining walls (secant piles, d-walls, soilmix, nails)
- Stability control methods (anchors, struts, decks)
- Sealing of deep excavations below groundwater level
- Design principles and geotechnical data needed
- Case studies of advanced design using FE 3D
- Lessons learned from challenging applications
- Q&A

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Coffee break / 11:30 - 12:00

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Agenda / 12:00 - 13:30

Underpinning of buildings and compensation grouting (by Prof. Michał Topolnicki, PhD, Clemens Kummerer, PhD)

- Principles of jet and compensation grouting
- Creating space below existing buildings
- Protecting deep foundations
- Underpinning of historical buildings
- Monitoring of settlements and deformations
- Case studies of advanced application
- Lessons learned from challenging projects
- Q&A

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Lunch break / 13:30 - 14:30

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Agenda / 14:30-16:00

The use of ground improvement for heavily loaded objects by Prof. Michał Topolnicki, PhD

- Principles of selected GI methods (vibrocompaction, stone columns, dynamic compaction, wet deep and mass mixing, rigid inclusions)
- Design practice and execution
- Case studies illustrating the use of GI as an alternative to conventional piling
- Benefits from GI applications and reduced CO_2 emission
- Lessons learned from challenging projects
- Q&A

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Training seminar / Apmācību seminārs

Deep Foundations and Excavation Control in Dense City Environments – Challenges and Possibilities (Session 1)

Dziļie pamati un rakšanas kontrole blīvi apbūvētā pilsētas vidē – izaicinājumi un iespējas (Sadaļa Nr.1)

Prof. Michał Topolnicki, PhD,
Daniel Dymek, MSc., Grzegorz Sołtys, PhD (Poland)

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Deep foundations and excavation control in dense city enviroments

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Deep foundations and excavation control in dense city enviroments

What do we have to take into consideration?

- size, shape and depth of excavation (geometry)
- soil and groundwater conditions
- surrounding buildings and structures (geometry, loads and overall condition)
- geotechnical techniques (advantages & disadvantages, equipment limitations)
- structural and construction loads
- design, execution and testing standards/guidelines
- materials
- design modeling possibilities and limitations
- other boundary conditions
- local experience

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Geotechnical Techniques vs. Machines/Equipment

Source:
https://www.bauer-equipment.com

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Geotechnical Techniques vs. Machines/Equipment

Source: https://www.liebherr.com

Rig	Technique	Max. diameter	Max. drilling depth			
			12.5 m leader		14.5 m leader (XL)	
			-	Kelly +4	-	Kelly +4
		[mm]	[m]			
LRB 125	CFA (with cleaner)	600	14.4	18.4	16.4	20.4
	CFA (without cl.)		?	?	?	?
	CCFA	620	13		15	
	SDP	?	?		?	
	VDP (ring vibr.)	356-508	25		27	
	Precast pile	-	13.5		14	
	Soil mixing	-	15.2		17.2	
	Sheet pile (vibr.)	-	15.2		17.2	
	Predrill	500	15.2		17.2	

Rig	Technique	Max. diameter	Max. drilling depth
			18/21/24 m leader
		[mm]	[m]
LRB 155	CFA (with cleaner)	700	16
	CFA (without cl.)		17.5
	CCFA	620	15
	SDP	?	?
	VDP (ring vibr.)	356-508	34
	Precast pile	-	21
	Soil mixing	-	17.5
	Sheet pile (vibr./press)	-	21
	Predrill	800	21

Rig	Technique	Max. diameter	Max. drilling depth
			21/24/27/30 m leader
		[mm]	[m]
LRB 255	CFA (with cleaner)	1000	21.5
	CFA (without cl.)		23
	CCFA	900	18.5
	SDP	?	?
	VDP (ring vibr.)	356-610	40
	Precast pile	-	27
	Soil mixing	-	?
	Sheet pile (vibr./press)	-	28
	Predrill	?	?

Rig	Technique	Max. diameter	Max. drilling depth			
			22.2 m leader		27.2 m leader (XL)	
			-	Kelly +10	-	Kelly +10
		[mm]	[m]			
LRB 355	CFA (with cleaner)	1200	19.6	29.6	24.6	34.6
	CFA (without cl.)		?	?	?	?
	CCFA	900	21		26 (23)	
	SDP	600	21	31	26	36
	VDP (ring vibr.)	356-610	35		40	
	Precast pile	-	19		24	
	Soil mixing	-	20.5		25.5	
	Sheet pile (vibr.)	-	21		26	
	Predrill	?	?		?	

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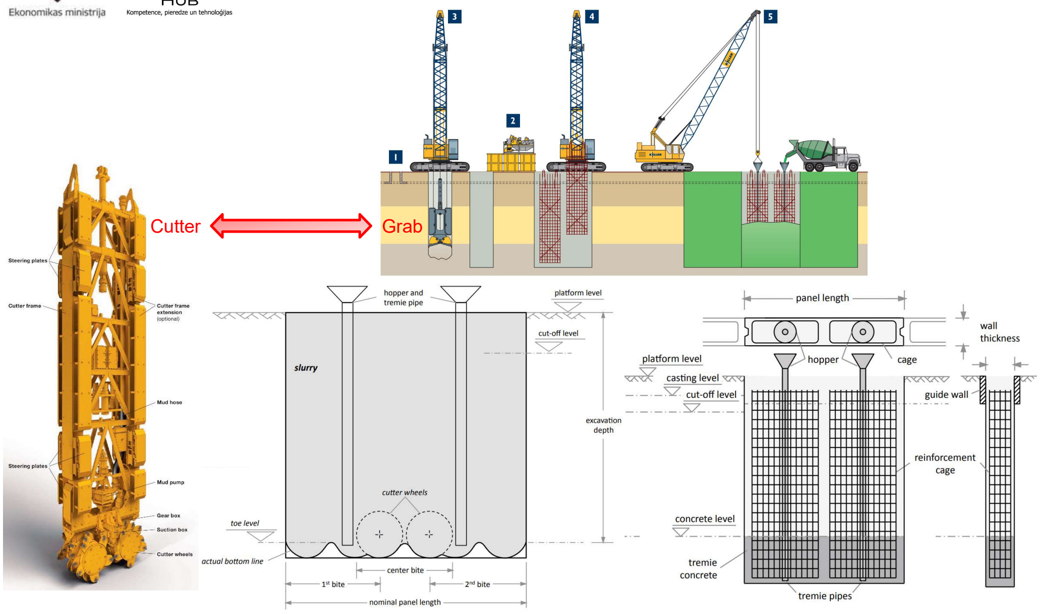
Diaphragm walls (D-walls)



1 GUIDE WALLS
Guide walls are built of reinforced concrete and fulfil the following functions:

- Stabilizing the upper part of the diaphragm-wall
- Reflecting the geometry of the diaphragm walls and they ensure their vertically (they guide the grab during excavation)
- Function as a bearing for extraction forces when recoverable joints are used
- Enabling the required level of supporting slurry to be maintained to stabilize the open trench

2 PREPARATION OF THE SUPPORTING SLURRY
Diaphragm walls are stabilized by the hydrostatic pressure exerted by the supporting slurry on the trench walls, and by the ingress of the slurry into the soil (bentonite mud filter cake). The materials used in the slurry are usually based on bentonites or specific polymers.

3 EXCAVATION OF DIAPHRAGM-WALL PANEL
In plan view, diaphragm walls are divided into primary and secondary panels. The design length of the panel is generally between 3 and 7 m; but can be increased up to 10 meters in specific conditions.

4 INSTALLATION OF REINFORCEMENT CAGES
The reinforcement of a single panels can consist of reinforcement cage(s). Care is taken that the reinforcement of the panels at any single point is not excessively dense, in order to ensure the necessary flow of concrete through the reinforcement. The reinforcement cages are positioned using cranes.

5 CONCRETING OF PANELS
The panels is concreted immediately after the reinforcement cage is inserted. The concreting is performed without interruption. The displaced supporting slurry is pumped into a special storage facility where it is regenerated for further use. To ensure a watertight seal between adjacent panel, specially designed seals are used for the joints between the panels when applicable.

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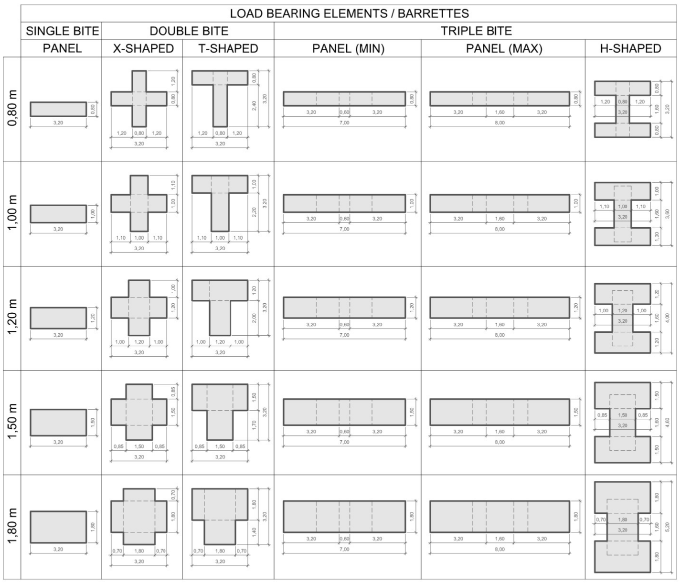
Diaphragm walls (D-walls)



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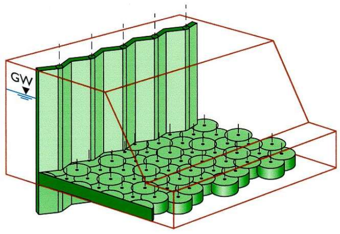
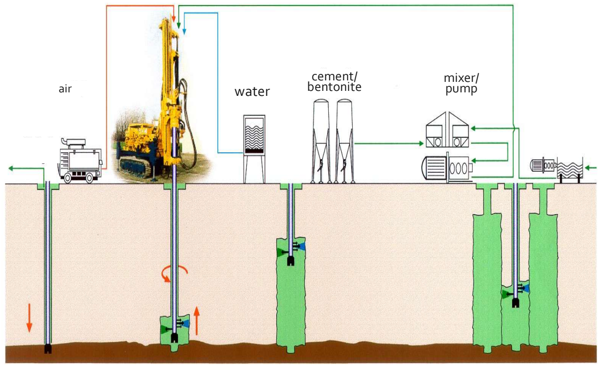
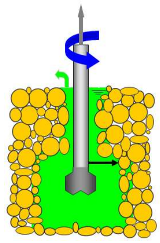
Jet Grouting (walls, slabs & other sealings)







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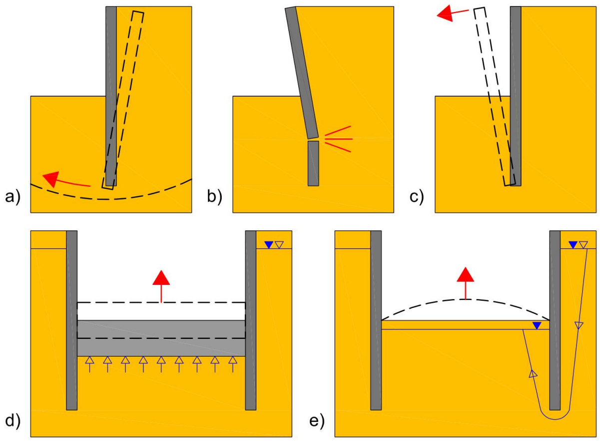
Excavation control – what do we check?

ULTIMATE LIMIT STATES (ULS)

- (a) Geotechnical (external)
- (b) Structural (internal)
- (c) Equilibrium (stability)
- (d) Uplift
- (e) Hydraulic heave

SERVICEABILITY LIMIT STATES (SLS)

- Displacement, deflection, deformation
- Cracking
- Vibration



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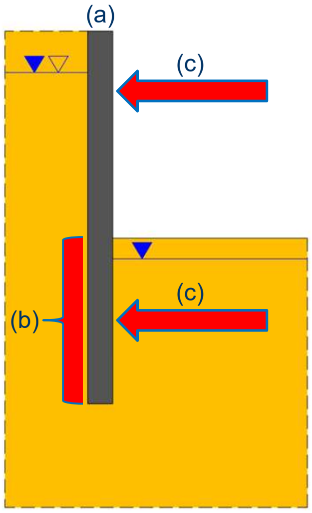
Excavation control – how do we deal with SLS?

Control of horizontal displacement, deflection, deformation

- (a) Stiffness
  - Shape of excavation
  - Shape of retaining wall
  - Materials
- (b) Embedment depth
- (c) Type and level of retaining wall supports
  - Above excavation level
  - Below excavation level



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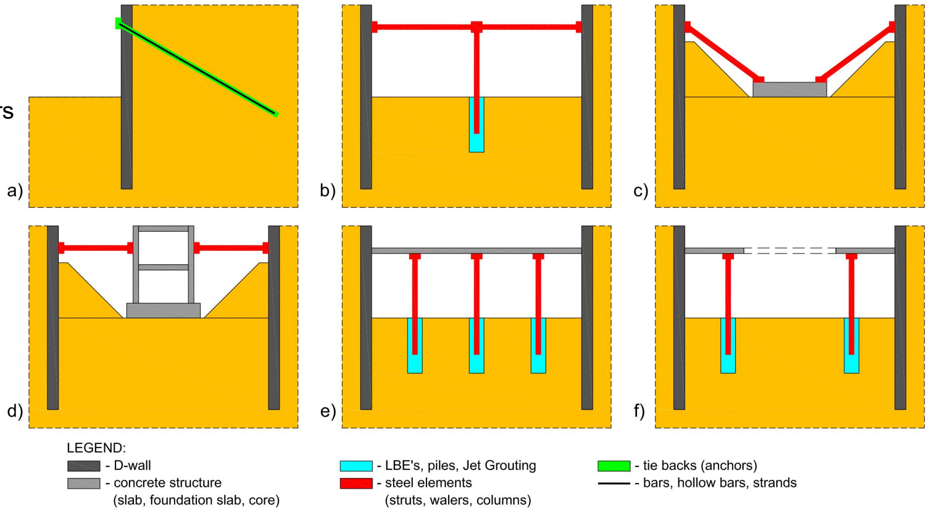
Excavation control – how do we support walls?

- (a) Active or passive anchors
- (b) Horizontal steel struts
- (c) Inclined steel struts
- (d) Core structure support
- (e) Full slab support
- (f) Partial slab support



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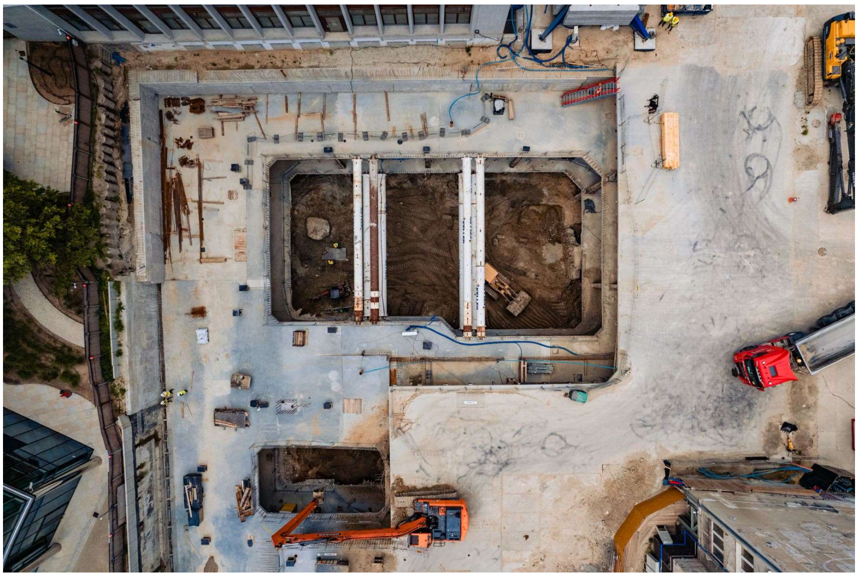
Excavation control – how do we suport a wall?



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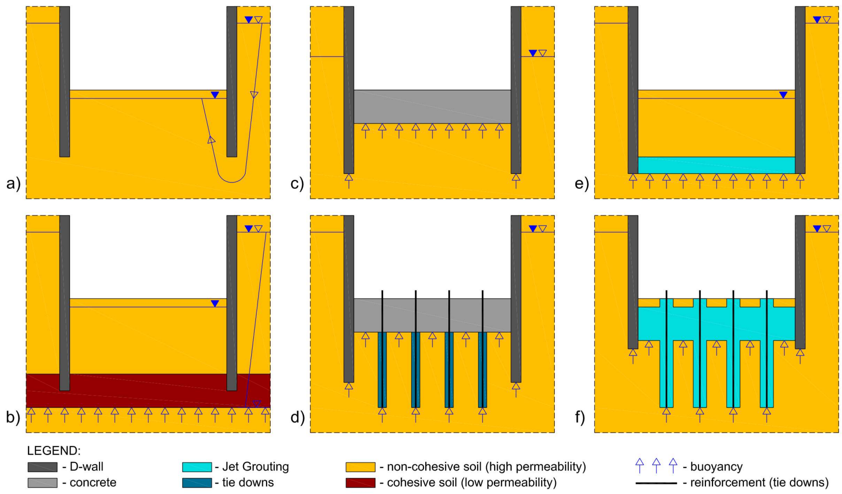
Excavation control – how do we deal with groundwater?

- (a) Dewatering
- (b) Natural cut-off
- (c) Tremie pipe concrete plug
- (d) Jet Grouting plug
- (e) Anchored tremie pipe concrete plug
- (f) Anchored Jet Grouting plug



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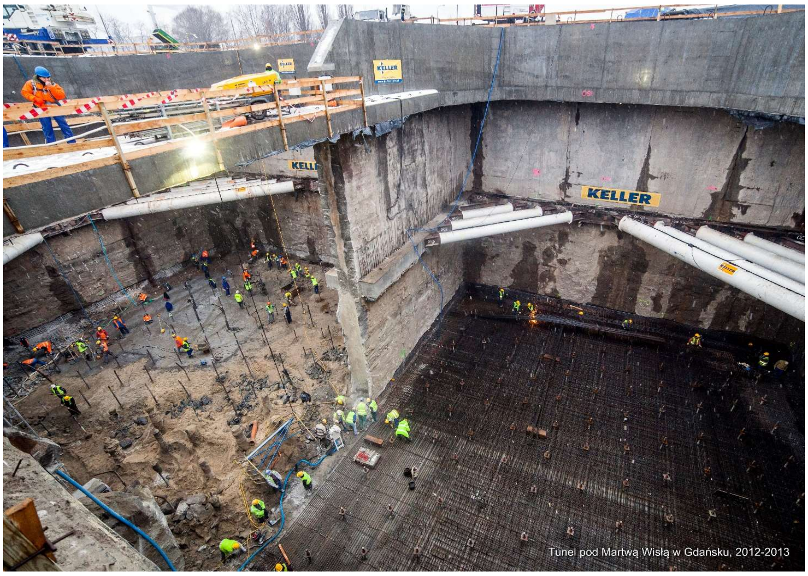
Excavation control – how do we deal with groundwater?



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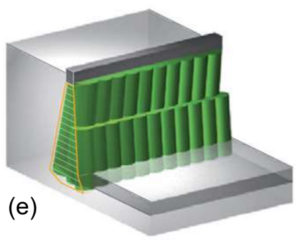
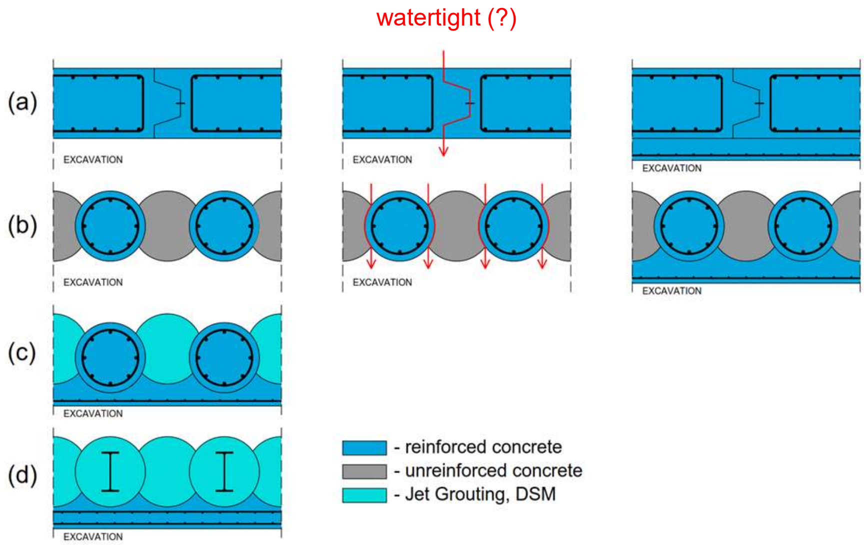
Retaining walls – watertight solutions

- (a) Diaphragm wall
- (b) Secant pile wall
- (c) Combined secant pile wall
- (d) Grouted secant pile wall
- (e) Jet Grouting underpinning
- Sheet pile wall


(e)



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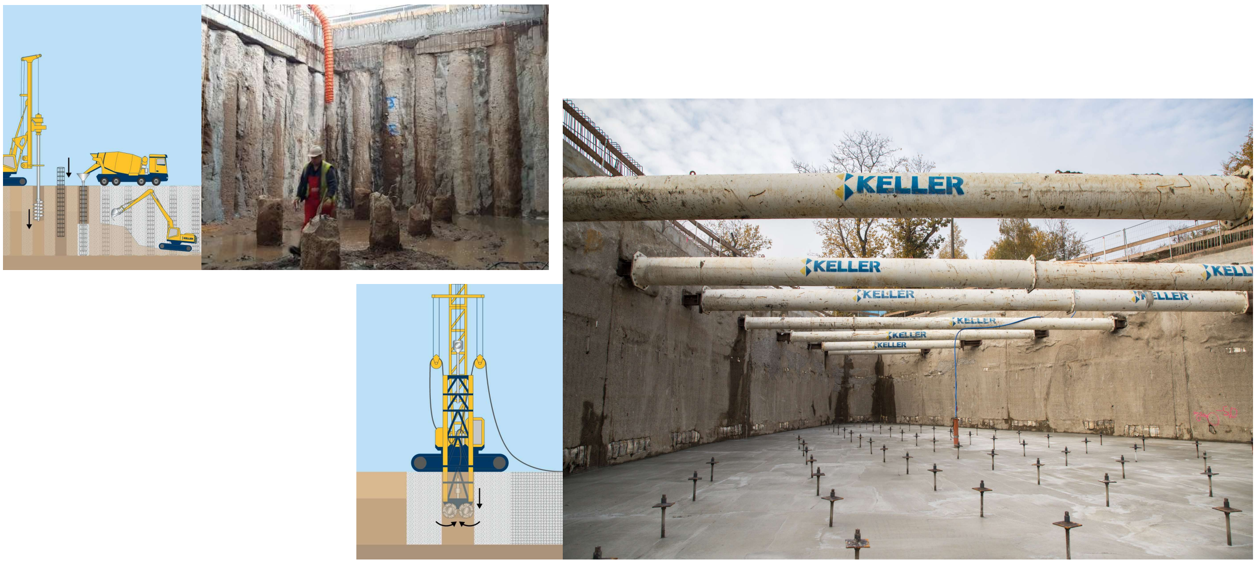
Retaining walls – watertight solutions



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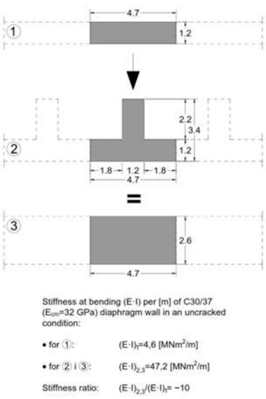
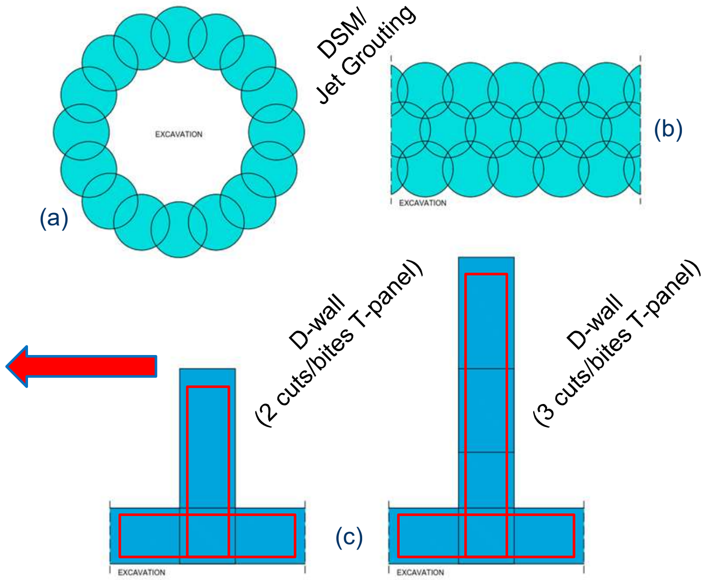
Excavation control – how do we make stiffer retaining walls?

- (a) Circular shafts
- (b) Massive walls
- (c) T-panels





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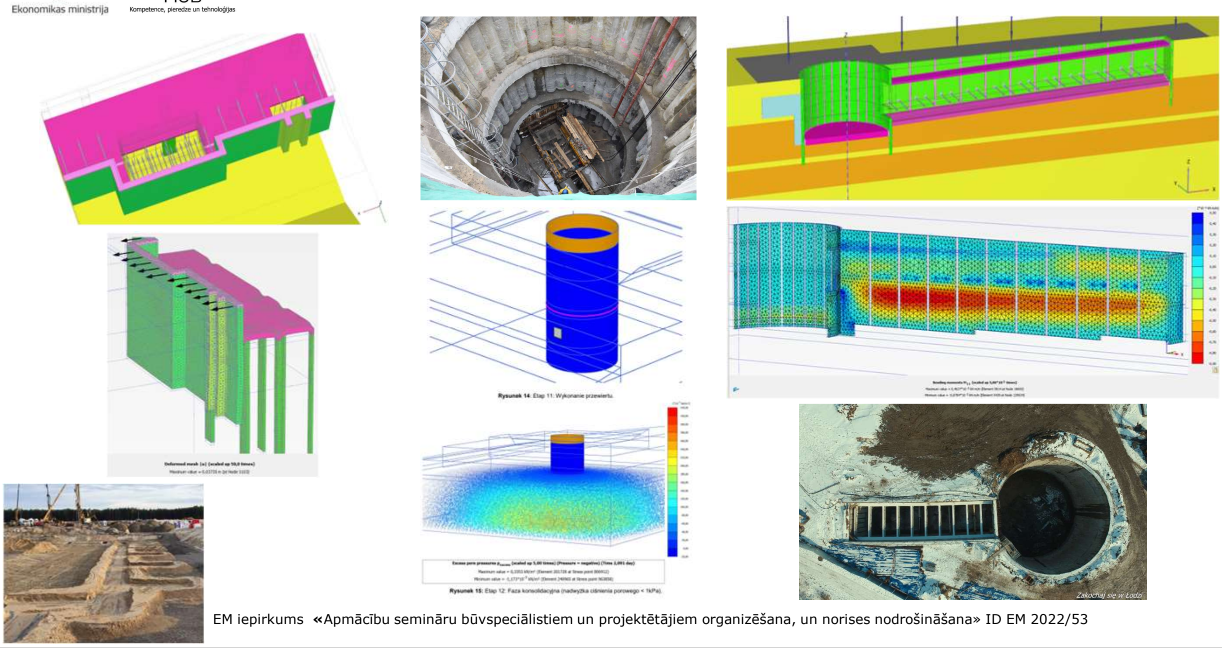
Excavation control – how do we make stiffer retaining walls?



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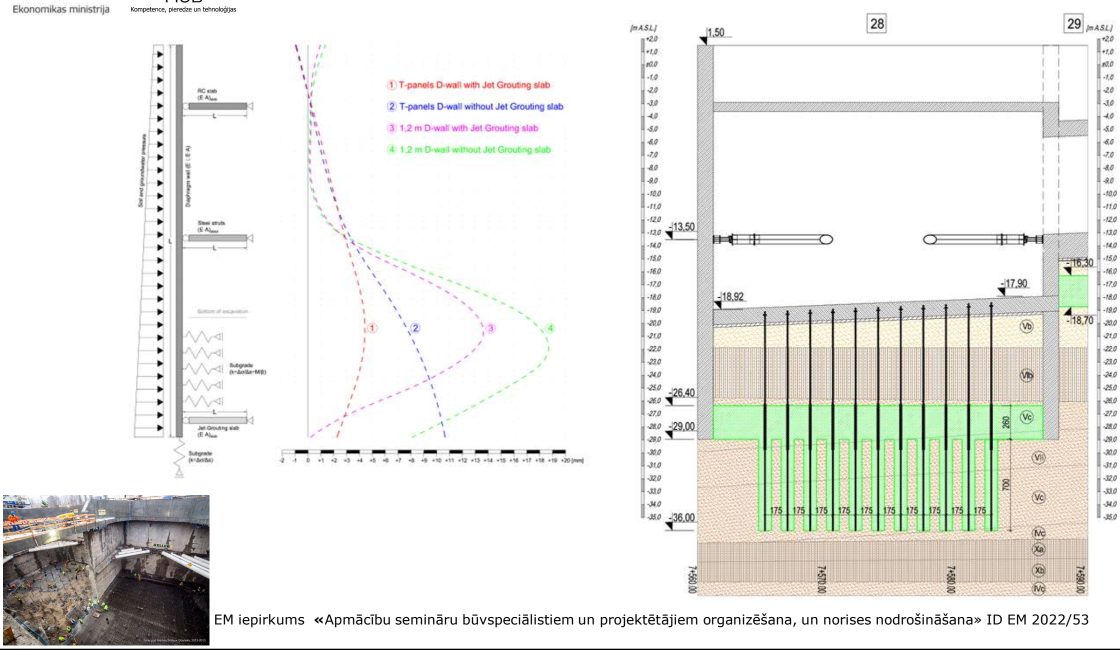
Excavation control – how do we make stiffer retaining walls?



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Excavation control – materials

- (a) Concrete
- (b) Grout
- (c) Grout + Steel (H-beam)

(a)

	Strength classes for concrete														Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)} \le C50/60$; $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60
$f_{ctk,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk;0,05} = 0,7\times f_{ctm}$ 5% fractile
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	$f_{ctk;0,95} = 1,3\times f_{ctm}$ 95% fractile
E_{cm} (GPa)	27	29	30	31	32	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0,3}$ (f_{cm} in MPa)
ε_{c1} (‰)	1,8	1,9	2,0	2,1	2,1	2,25	2,3	2,4	2,45	2,5	2,6	2,7	2,8	2,8	see Figure 3.2 ε_{c1}(‰) $= 0,7 f_{cm}^{0,31} < 2,8$
ε_{cu1} (‰)	3,5									3,2	3,0	2,8	2,8	2,8	see Figure 3.2 for $f_{ck} \ge 50$ Mpa ε_{cu1}(‰) $=2,8+27[(98-f_{cm})/100]^4$
ε_{c2} (‰)	2,0									2,2	2,3	2,4	2,5	2,6	see Figure 3.3 for $f_{ck} \ge 50$ Mpa ε_{c2}(‰) $=2,0+0,085(f_{ck}-50)^{0,53}$
ε_{cu2} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.3 for $f_{ck} \ge 50$ Mpa ε_{cu2}(‰) $=2,6+35[(90-f_{ck})/100]^4$
n	2,0									1,75	1,6	1,45	1,4	1,4	for $f_{ck} \ge 50$ Mpa $n=1,4+23,4[(90-f_{ck})/100]^4$
ε_{c3} (‰)	1,75									1,8	1,9	2,0	2,2	2,3	see Figure 3.4 for $f_{ck} \ge 50$ Mpa ε_{c3}(‰) $=1,75+0,55[(f_{ck}-50)/40]$
ε_{cu3} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.4 for $f_{ck} \ge 50$ Mpa ε_{cu3}(‰) $=2,6+35[(90-f_{ck})/100]^4$

if: $M_k > M_{cr} = W_c \cdot f_{ctm}$

then:

Crack Width Limits

Recommended values of w_{max}		
Exposure class	RC or unbonded PSC members	Prestressed members with bonded tendons
	Quasi-permanent load	Frequent load
X0,XC1	0.3*	0.2
XC2,XC3,XC4	0.3	
XD1,XD2,XS1, XS2,XS3		Decompression
* Does not affect durability, may be relaxed where appearance is not critical (eg use 0.4 mm)		

Stiffness at bending ($E \cdot I$) decreases

unreinforced (a)&(b): PLAXIS Concrete model

The yield functions can be formulated in terms of principal stresses in relation to the uniaxial compressive and tensile yield stresses, f_{cy} and f_t, as:

$$F_c = \frac{\sigma_1 - \sigma_3}{2} + \frac{\sigma_1 + \sigma_3 - 2\sigma_{rot}}{2} \frac{f_{cy}}{2\sigma_{rot} + f_{cy}} \qquad Eq. [293]$$

$$F_t = \sigma_1 - f_t \qquad Eq. [294]$$

where

σ_{rot} = Intersection of the Mohr-Coulomb failure envelope and the isotropic axis.

For a given maximum inclination of the Mohr-Coulomb envelope, σ_{rot} can be written as:

$$\sigma_{rot} = \frac{f_c}{2}\left(\frac{1}{\sin(\varphi_{max})} - 1\right) \qquad Eq. [295]$$

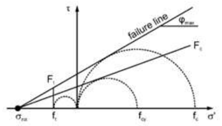

Figure 62: Yield surfaces and failure envelope for Concrete model

(b)  f_{ck} < 10 MPa

E = „factor"$\cdot f_{ck}$ < 10 GPa

(c)  $E = (E_{col} \cdot I_{col} + E_{steel} \cdot I_{steel})/I_{col}$

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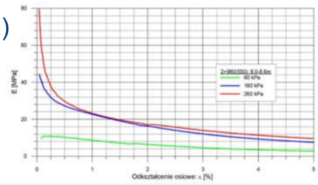
Excavation control – design modeling

- (a) Proper soil data
- (b) Classic vs. FEM 2D analysis
- (c) 2D vs. 3D FEM analysis
- The more the better?

(a)



Wykres 6.1. Wykres zmian wartości modułu odkształcenia E w zależności od odkształcenia osiowego ε

7. Dodatkowe parametry wyprowadzone

Tabela 1: Parametry do modelu Hardening Soils

Lp.	Próbka	[kPa]	[°]	c' [kPa]	[kPa]	[MPa]	[MPa]	ψ [°]	[MPa]	[MPa]	m [-]	[MPa]	[MPa]
1	2+980 (550)_60	60	29,3	9,4	160	89,44	88,00	4,88	16,59	21,49	0,689	17,65	19,56
2	2+980 (550)_160	160				89,87			27,21			24,76	
3	2+980 (550)_260	260				84,69			20,66			16,28	

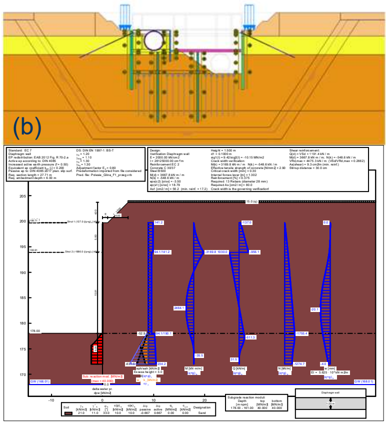
E_{ur}^{ref} – referencyjny moduł odciążenie – obciążenie,

E_{oed}^{ref} – referencyjny moduł edometryczny,

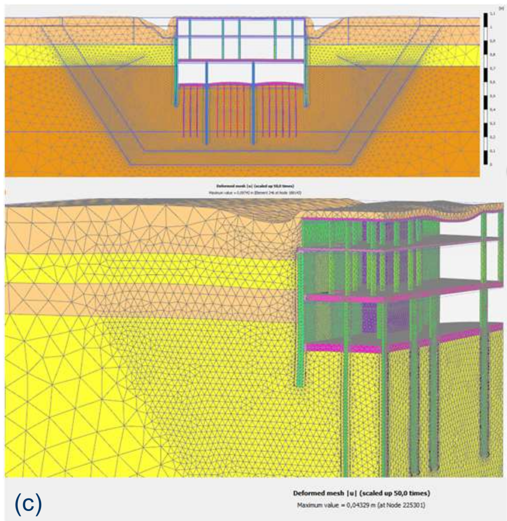
E_{50}^{ref} – sieczny moduł odpowiadający 50% wytrzymałości,

ψ [°] – kąt dylatancji

(b)



(c)



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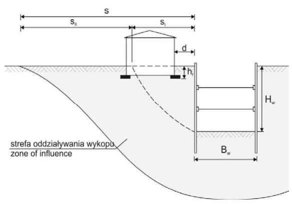
Excavations – zone of influence

Comparison of the zones of influence according to different authors (Godlewski, 2016) in light of ITA-AITES recommendations (2014)

Źródło Source	Clough i O'Rourke (1990)		Instrukcja ITB nr 376 (Kotlicki i Wysokiński 2002)				Wytyczne (ITA-AITES, 2014)	
Rodzaj gruntów w podłożu Subsoil type	piaski sands	iły i gliny clays and tills	piaski sands		iły clays		bez względu na rodzaj podłoża despite subsoil type	
			S_I	S_{II}	S_I	S_{II}	S_I (active zone)	S_{II} (vigilance zone)
Zasięg strefy oddziaływań Range of zones of influence	1,5÷2 *H*	2÷4 *H*	0,5 *H*	2 *H*	1 *H*	3÷4 *H*	stacje – stations: 1 *H* lub 50 m tunele – tunnels: 1 *H*+1/2 *D* lub 50 m	stacje i tunele – stations and tunnels: 2 *H* lub100 m

Objaśnienia – Explanations:
H – głębokość wykopu lub posadowienia – depth of excavation or foundation level [m];
D – średnica tunelu – tunnel diameter [m].

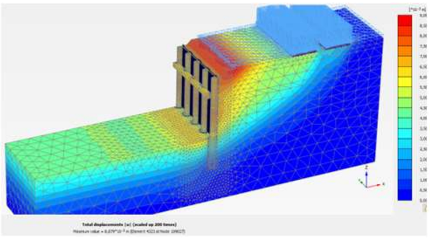
Rodzaj gruntów Soil type	Strefa oddziaływań Zone of influence S_I	Strefa oddziaływań Zone of influence S_{II}
Piaski Sands	0,5 H_w	2,0 H_w
Gliny Glacial tills	0,75 H_w	2,5 H_w
Iły Clays	1,0 H_w	3÷4 H_w

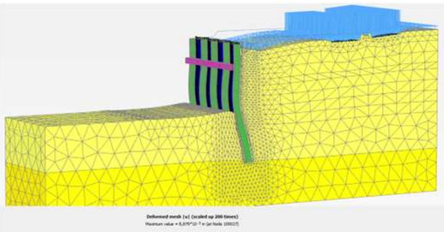


Objaśnienia – Legend:
H_w i B_w – głębokość i szerokość wykopu – depth and width of excavation
S – zasięg strefy oddziaływania wykopu – range of influence zone
S_I – zasięg strefy bezpośredniego oddziaływania – range of active zone influence
S_{II} – zasięg strefy wpływów wtórnych – range of vigilance zone influence
d – odległość budynku od obudowy – distance of the structure from the excavation
h_f – głębokość posadowienia budynku – foundation depth

The range of influence of DF by different researchers

Źródło	Zasięg	Uwagi dodatkowe
[Breymann H. i inni 1997]:	1,5–2 *H*	grunty niespoiste: piaski drobne, średnie i żwiry
[Simpson B. i inni 1979]	2–2,5 *H*	iły londyńskich i gliny zwałowe
	2–3 *H* (maks. 5 *H*)	mocne grunty spoiste
[Clough G., O'Rourke T. 1998]	2–4 *H*	iły londyńskie i gliny zwałowe
[Kotlicki W., Wysokiński L. 2002]	2,0 *H*	w piaskach
	2,5 *H*	w glinach
	3–4 *H*	w iłach
norma rosyjska [TSN 50-302-2004]	30 m	przy wstępnej analizie, przy pełnej analizie – komentarz w tekście
norma rosyjska [SP22.13330.2011] przy wstępnej analizie	5 *H*	przy kotwionej konstrukcji zabezpieczającej wykop, ale nie więcej niż 2 Lk, gdzie Lk– długość kotwy (cięgna i buławy)
	4 *H*	przy stalowej konstrukcji zabezpieczającej wykop pracującej, jako wspornik lub rozpartej (stalowymi rozporami lub zastrzałami), a także przy wykonywaniu wykopu otwartego
	3 *H*	przy konstrukcji w technologii ścian szczelinowych lub ścian z pali, pracującej jako wspornik lub rozpartej (stalowymi rozporami lub zastrzałami)
	2 *H*	przy konstrukcji w technologii ścian szczelinowych lub ścian z pali i wykonywaniu wykopu metodą podstropową





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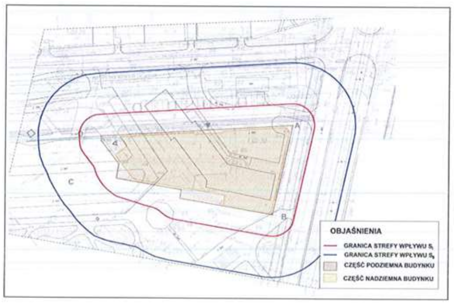
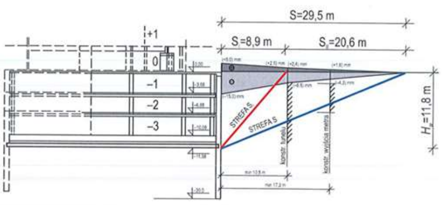
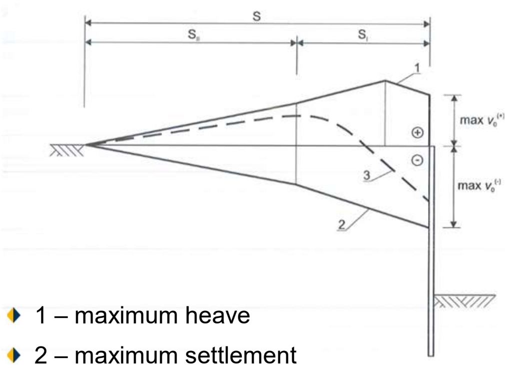
Excavations – zone of influence





- S_1 – active influence zone
- S_2 – vigilance influence zone



- 1 – maximum heave
- 2 – maximum settlement
- 3 – average vertical displacement

Source:
Protection of structures adjacent
to deep excavations. Guideline.
ITB, Warsaw, 2020

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Excavations – existing buildings and structures

Approximate ultimate displacements for typical structures

Sensitivity	Type of structure	Settlement		Relative rotation	Tilt
		$s_{k,SLS}$	$s_{k,ULS}$	β	ω
		[mm]		[%]	
Highest	masonary buildings without tie beams, with wooden or Klein ceillings	5÷7	15÷18	0,05	0,1
High	masonary buildings with RC or beam-and-block ceillings, precast construction buildings	7÷9	20÷25	0,075	0,2
Normal	RC buildings	9÷11	25÷35	0,15	0,3

Sensitivity	Type of installation	Settlement $s_{k,SLS}$ [mm]
Lowest	single cables	200
Low	multiple cables in bundles	150
	water pipes	100
	100 mm gas pipes	100
Normal	400 mm gas pipes	50
High	sewer pipes	10÷25

Approximate ultimate displacements for typical underground installations

Source:
Protection of structures adjacent to deep excavations. Guideline. ITB, Warsaw, 2020

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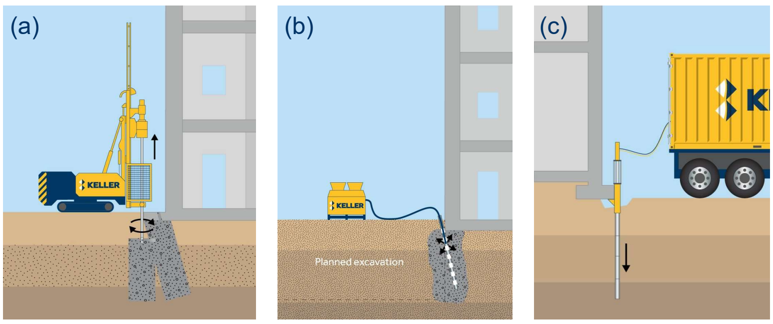
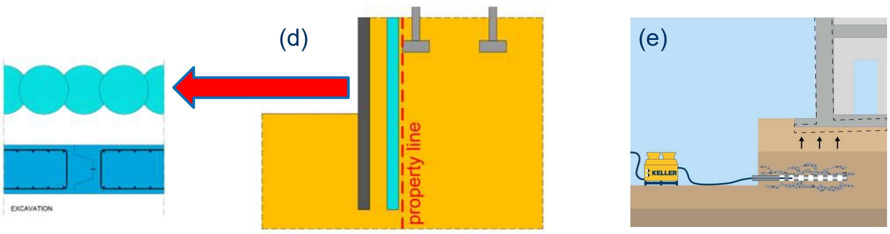
Existing buildings and structures – how to protect them?

- (a) Jet Grouting underpinning
- (b) Permeation Grouting
- (c) Micropiles
- (d) Additional protective wall
- (e) Compensation Grouting





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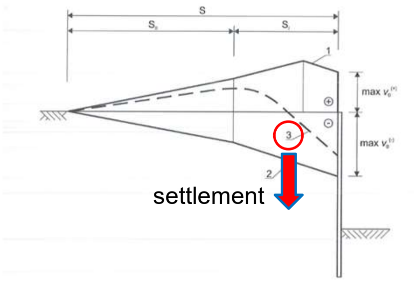
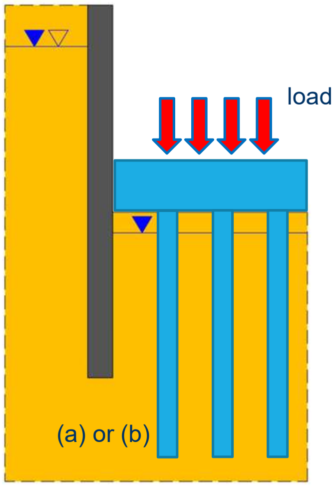
Deep foundations – how do we deal with SLS?

Control of vertical displacement
(heave & settlement)

- (a) soil improvement
- (b) piles or piled rafts





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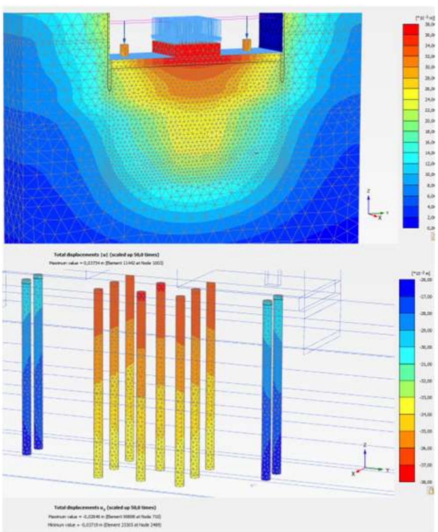
Deep foundations – piled rafts



Reduction of settlement

Optimization of foundation slab

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Case studies of advanced design using FE 3D

Scope of case studies presentation

- Short introduction,
- Presentation of 3 building designed with help of 3D FE,
- Soil condition and applied solution for slab and excavation,
- Description of the applied constitutive models,
- Description of 3D geotechnical model,
- Results of FE prediction for unfinished (under construction) building with partial deformation measurements,
- Results of FE prediction and measured settlements for 2 finished budlings.

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Case studies of advanced design using FE 3D

Short introduction

Advanced geotechnical design **using** **Finite Element Method 3D**

3D Always with 2D models

PLAXIS 3D CONNECT Edition PLAXIS 2D CONNECT Edition

Portions © 2021 Bentley Systems,

Advanced modeling for non-linear soil and soil-structure interaction especially:

- Small strain and large strain (typical engineering range) behaviour
- Rock-soil mechanics and „classic" soil mechanics with stifft and soft material behaviour
- Time dependent (consolidation) and creep, drain and undrain calculation, dynamic analysis
- Deformation coupled with ground water flow analysis (steady state or transient)
- Various standard constitutive material models and possibility to use user-defined models („dll-models")
- Possibilities for automatization with macros and Phyton scripts for pre and post processing
- Vitrual soil-lab tools (triaxial, oedometer and others), easy parameter verification
- Sensitivity Analysis & parameter variation
- Interaction with „CAD" programs to exchange geometry data

*** used with case studies examples ***

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Case studies of advanced design using FE 3D

Presentation of 3 building

Warsaw 5 years ago, Towarowa street source: google maps

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Case studies of advanced design using FE 3D

Presentation of 3 building

1. The Warsaw HUB
Height: 130m, 130m, 85m

Scope of works:
Complex Design: D-wall, jet-grouting, barrettes (raft-foundation)

- D-wall -(thickness **1,0**m, depth 30m)
- Barrettes instead of piles,
- Vertical waterproof Jet grounting slab

Scope of FE 3D calculation:

- Foundation settlements (pile raft)
- Providing spring stiffness for structural software (for a barrettes, D-wall, and soil)

2. Spinnaker
Height: 200m

Scope of works:
Complex Design: D-wall, jet-grouting, barrettes, (raft-foundation)

- D-wall -(thickness 0,8m, depth 23m)
- Barrettes instead of piles, Horizontal waterproof Jet grounting slab

Scope of FE 3D calculation:

- Foundation settlements (pile raft)
- Providing spring stiffness for structural software (for a barrettes, D-wall and soil)
- analysis of the impact on the near metro line

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Case studies of advanced design using FE 3D

Presentation of 3 building

3. The Bridge
Height: 174m

Scope of works:
Complex Design: D-wall, Jet Grouting, Barrettes, raft foundation
- D-wall -(thickness 1,0m and 0,8m, depth 30m)
- Barrettes instead of piles, horizontal Jet Grouting slab

Scope of FE 3D calculation:
- Foundation settlements (pile raft)
- excavation model, with additional 2D FE models
- Providing spring stiffness for structural software (for Barrettes, D-wall and soil)
- analysis of the impact on the near historic buildings with extended 2D cross-section analysis

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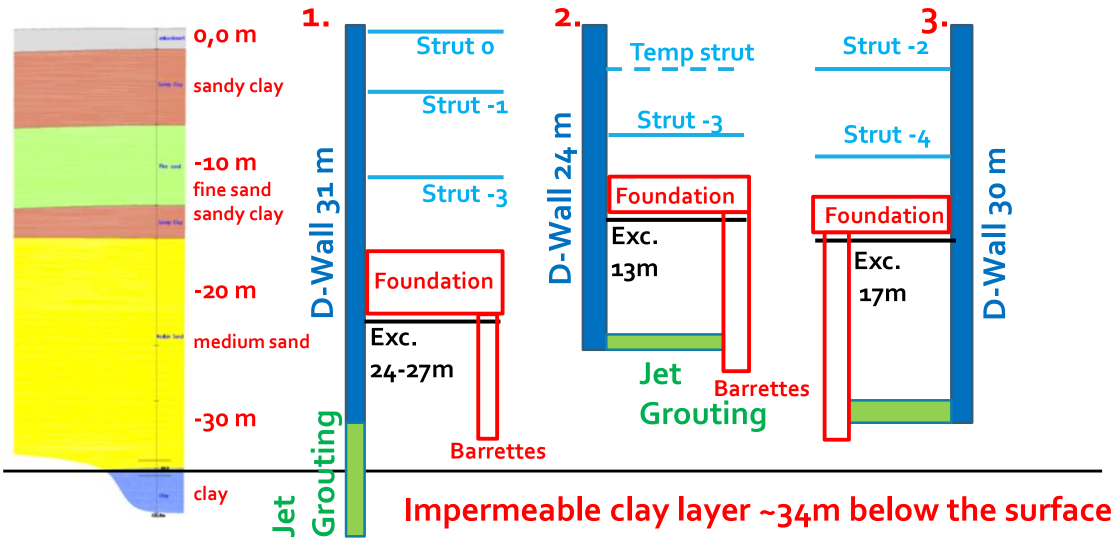
Case studies of advanced design using FE 3D

Soil condition and applied solution for foundation and excavation



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Case studies of advanced design using FE 3D

CPRF - Combined pile raft foundation

Barrettes (piles), diaphragm walls and the foundation slab together transfer the load to the ground.

It is not necessary to verify the bearing capacity of individual barrettes (piles) – as in the pile foundation system where the entire load is transferred by the piles.

Calculations provide:
- Settlements
- Structural forces in piles/barrettes/ D-walls

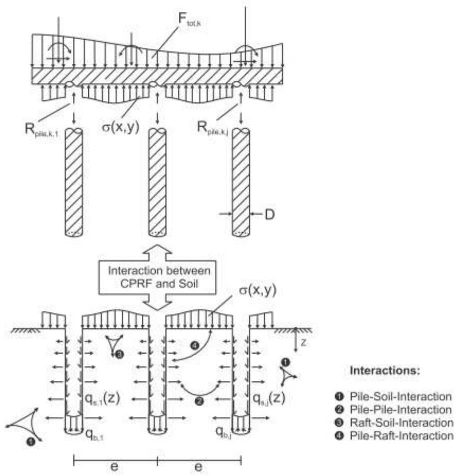

Fig. 1.1 Combined Pile Raft Foundation (CPRF) as a geotechnical composite construction and the interactions coining the bearing behaviour

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Case studies of advanced design using FE 3D

Range of applications for soil model according to Plaxis (Bentley)
A –The best standard model, B-Reasonable modeling, C-First order

Model	Analysis	SANDS	SILTS Dilatant Low compressible	SILTS Non-dilatant Compressible	CLAYS Degree of overconsolidation High Stiff clays	CLAYS Degree of overconsolidation Low	CLAYS Degree of overconsolidation Normal Soft clays
Mohr-Coulomb (Drucker-Prager)	SLS						
	ULS	C	D		D		
CAP	SLS	D	D	D	D	C	C
	ULS					C	C
Modified Cam-Clay	SLS			D		C	C
	ULS			C		C	C
HS-standard	SLS					A	A
	ULS	A	A	A	A	A	A
HS-small	SLS	B	B	B	B	B	B
	ULS	A	A	A	A	A	A
HS-Brick	SLS	A	A	A	A	A	A
	ULS	A	A	A	A	A	A

Recommendations for the model choice for different soils and two type analyzes: Serviceability Limit State (SLS) and Ultimate Limit State (ULS). Meaning of rating: (A) recommended, (B) recommended except situations when small strain reversals may occur and transient analyses, (C) can be used, (D) can be used but not recommended in terms of quality of results, empty grid cell means not applicable

Selected model for a soil: HS small & Hardening Soil

Selected model for D-Walls, Barrettes, Foundation Slab:
- **Linear elastic (for volume elements)**
- **Linear elasto-plastic for structure el.**

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Case studies of advanced design using FE 3D

Description of the applied constitutive model for soil ,

Hardening Soil:

- Stress dependent stiffness according to a power law
- Plastic straining due to primary deviatoric loading
- Plastic straining due to primary compression
- Elastic unloading / reloading
- Failure according to the Mohr-Coulomb failure criterion

HS small: Hardening Soil + small strain behaviour

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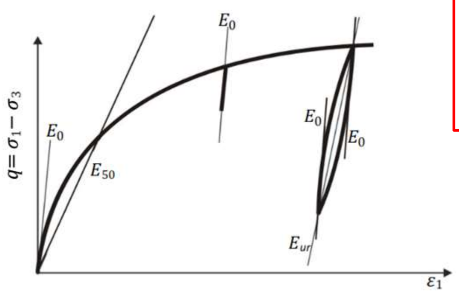
Case studies of advanced design using FE 3D

Description of the applied constitutive model for soil

HS small & Hardening Soil



Stiffness parameters E50, Eur, Eo, from q-eps curve from triaxial test

m	Power for stress-level dependency of stiffness	[-]
E_{50}^{ref}	Secant stiffness in standard drained triaxial test	[KN/m^2]
E_{oed}^{ref}	Tangent stiffness for primary oedometer loading	[KN/m^2]
E_{ur}^{ref}	Unloading / reloading stiffness from drained triaxial test	[KN/m^2]
$v_{0.7}$	Poisson's ratio for unloading-reloading	[-]
G_0^{ref}	Reference shear modulus at very small strains ($\varepsilon < 10^{-6}$)	[KN/m^2]
$\gamma_{0.7}$	Threshold shear strain at which $G_s = 0.722G_0$	[-]

Additional parameters for the HS-small model:
Go –based on correlation between small strain stiffness and stiffness at larger strains, Alpan (1970)
γ0.7 –based on stiffness recuction curver after Vucetic and Dobrey (1991)

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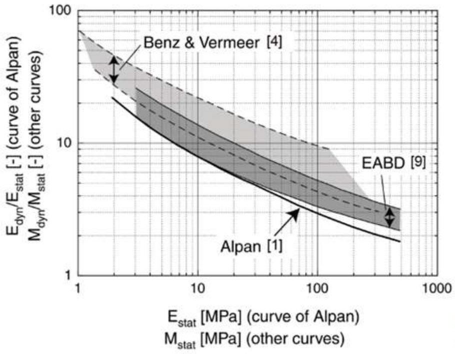
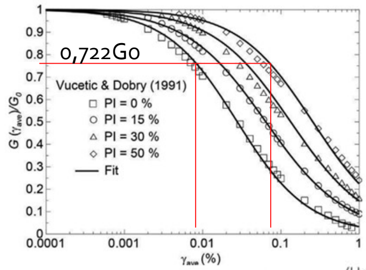
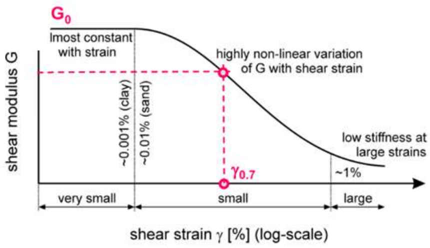
Case studies of advanced design using FE 3D



$$G_0^{ref} = E_0^{ref} / (2(1 + \nu_{ur}))$$

stiffness recuction curver after Vucetic and Dobry (1991)





(Hardin & Drnevich, 1972):

$$\gamma_{0.7} \approx \frac{1}{9G_0}\left[2c'(1+\cos 2\varphi') + \sigma_1'(1+k_0)\sin 2\varphi'\right]$$

where:
c' = drained cohesion [kN/m²]
ϕ' = drained angle of internal friction [deg]
k_0 = neutral earth pressure coefficient [-]
σ_1' = effective vertical stress (usually equal to σ_3' = 100 kPa) [kN/m²]

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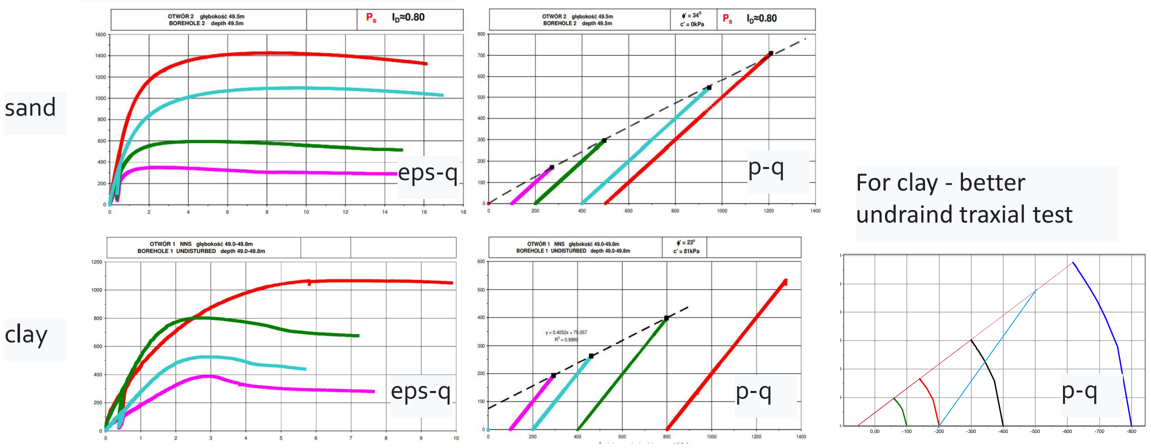
Case studies of advanced design using FE 3D

Realization of triaxial drain test for sand and clay, (3. The Bridge)

Stiffness parameters E50, Eo, m

Failure according to the Mohr-Coulomb failure criterion



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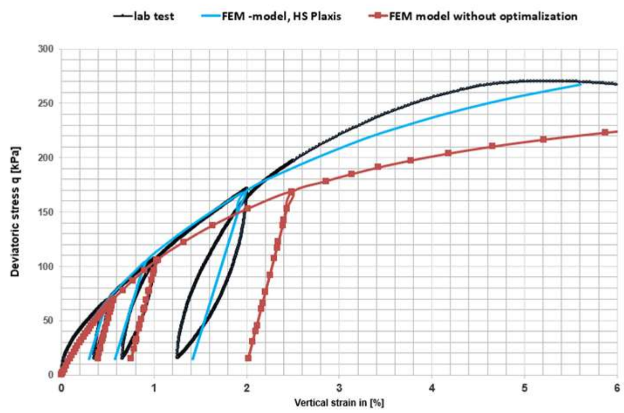
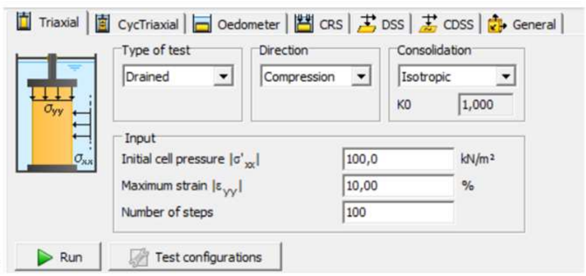
Case studies of advanced design using FE 3D

Optimalization of triaxial test for parametr selection with Plaxis Virtual Lab Test Tools





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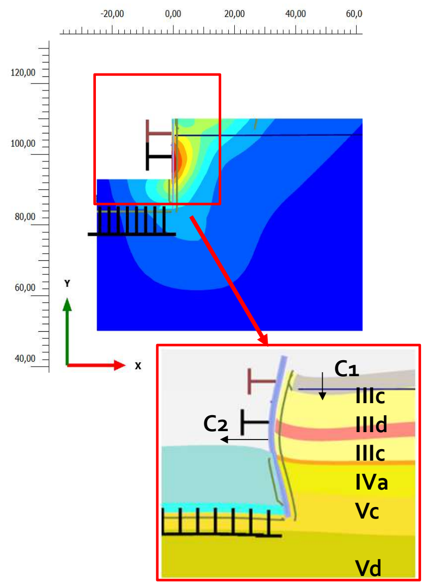
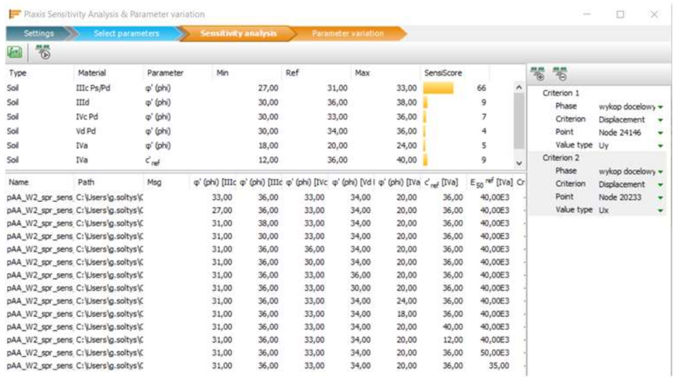
Case studies of advanced design using FE 3D
parameter variation





(C1) - Criterion 1: settlements of existing building
(C2) - Criterion 2: horizontal D-wall displacement

After Plaxis Sensitivity Analysis => IIIc

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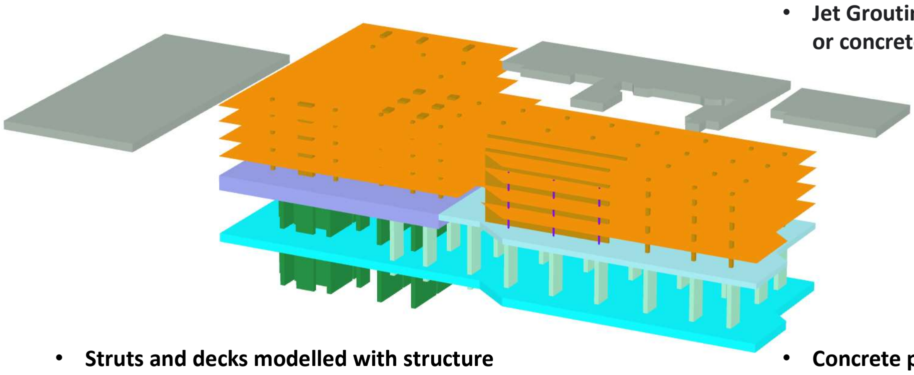
Case studies of advanced design using FE 3D

Description of geometry of 3D geotechnical model (3. The Bridge)

- **Foundation slab and barrettes modelled with volume elements (L-E model)**
- **Jet Grouting slab (volume elements, L-E or concrete model)**



- **Struts and decks modelled with structure elements (no volume elements)**
- **Concrete pillars, walls, building foundations modelled with volume elements (L-E model)**

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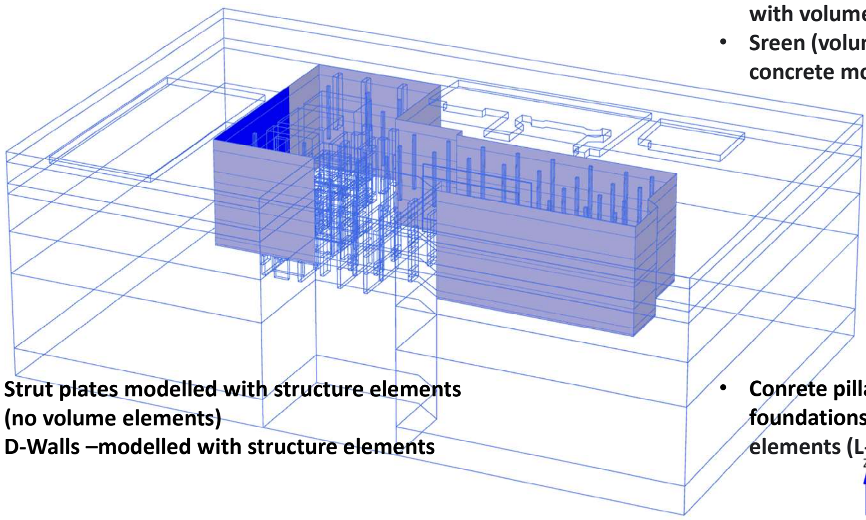
Case studies of advanced design using FE 3D

Description of geometry of 3D geotechnical model (3. The Bridge)

- **Foundation plate and barrets modelled with volume elements (L-E model)**
- **Sreen (volume elements, L-E or concrete model)**



- **Strut plates modelled with structure elements (no volume elements)**
- **D-Walls –modelled with structure elements**
- **Conrete pillars, walls, building foundations modelled with volume elements (L-E model)**

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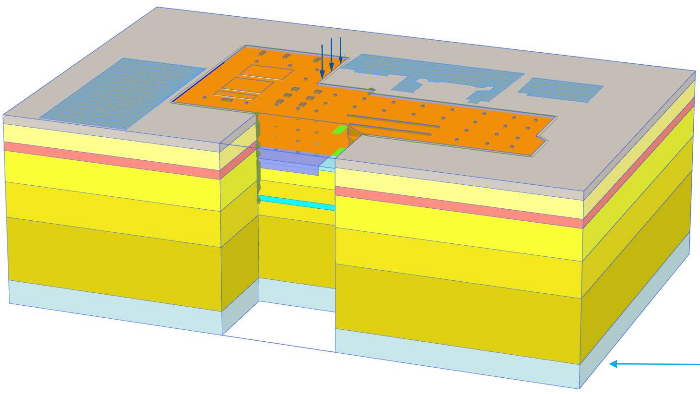
Case studies of advanced design using FE 3D

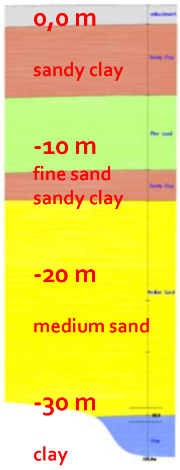
Description of geometry of 3D geotechnical model (3. The Bridge)



- HS-model
- +undrain behaviour

HS-Small models
+undrain /drain behaviour

HS or HS Small model with
undrain behaviour



To all volume and structures elements interface elements added
In interface element: strength and stiffness elements)

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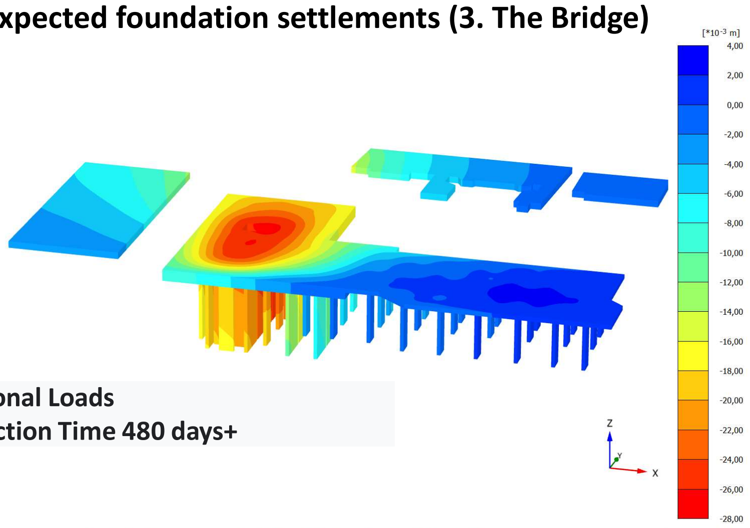
Case studies of advanced design using FE 3D expected foundation settlements (3. The Bridge)



Operational Loads
Construction Time 480 days+

Total displacements u_z (scaled up 200 times) (Time 473,0 day)
Maximum value = $3{,}578 \cdot 10^{-3}$ m (Element 99345 at Node 126340)
Minimum value = -0,02645 m (Element 106761 at Node 145061)

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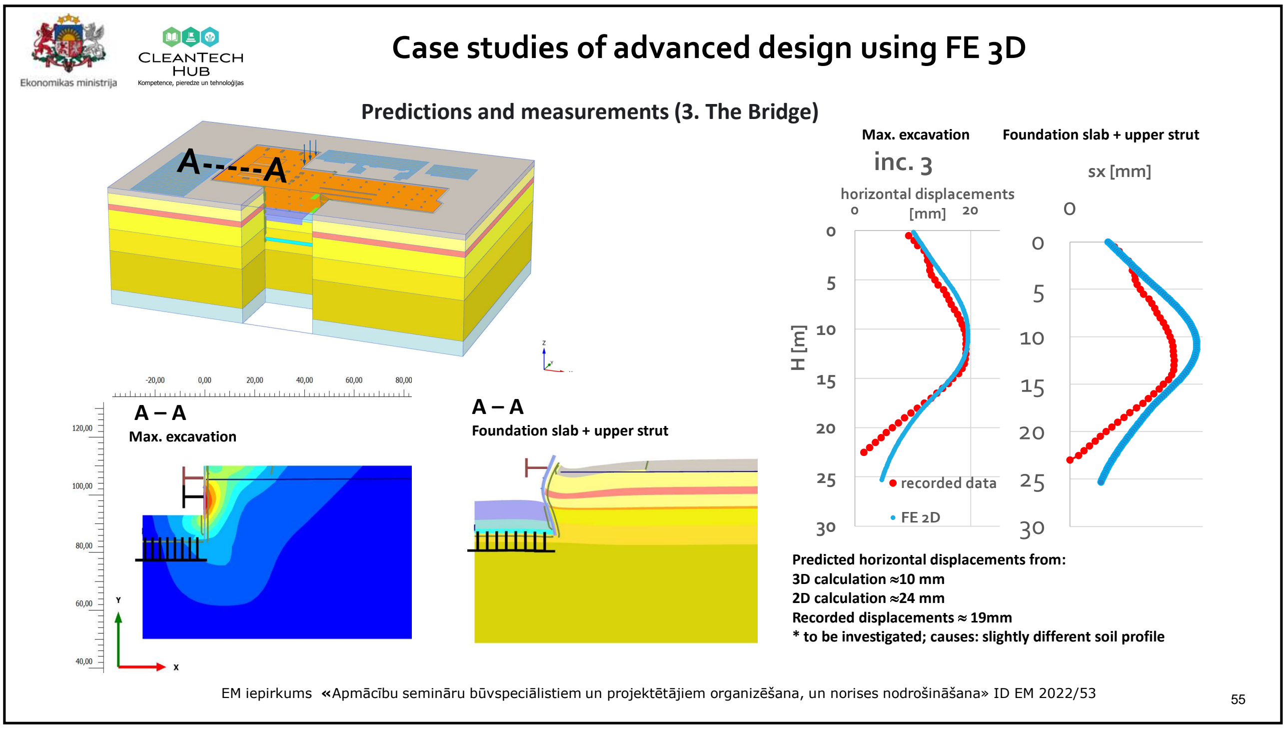
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Case studies of advanced design using FE 3D
Predictions and measurements (3. The Bridge)
A-----A
A – A
Max. excavation
A – A
Foundation slab + upper strut
Max. excavation
Foundation slab + upper strut
inc. 3
horizontal displacements [mm]
sx [mm]
H [m]
recorded data
FE 2D
Predicted horizontal displacements from:
3D calculation ≈10 mm
2D calculation ≈24 mm
Recorded displacements ≈ 19mm
* to be investigated; causes: slightly different soil profile
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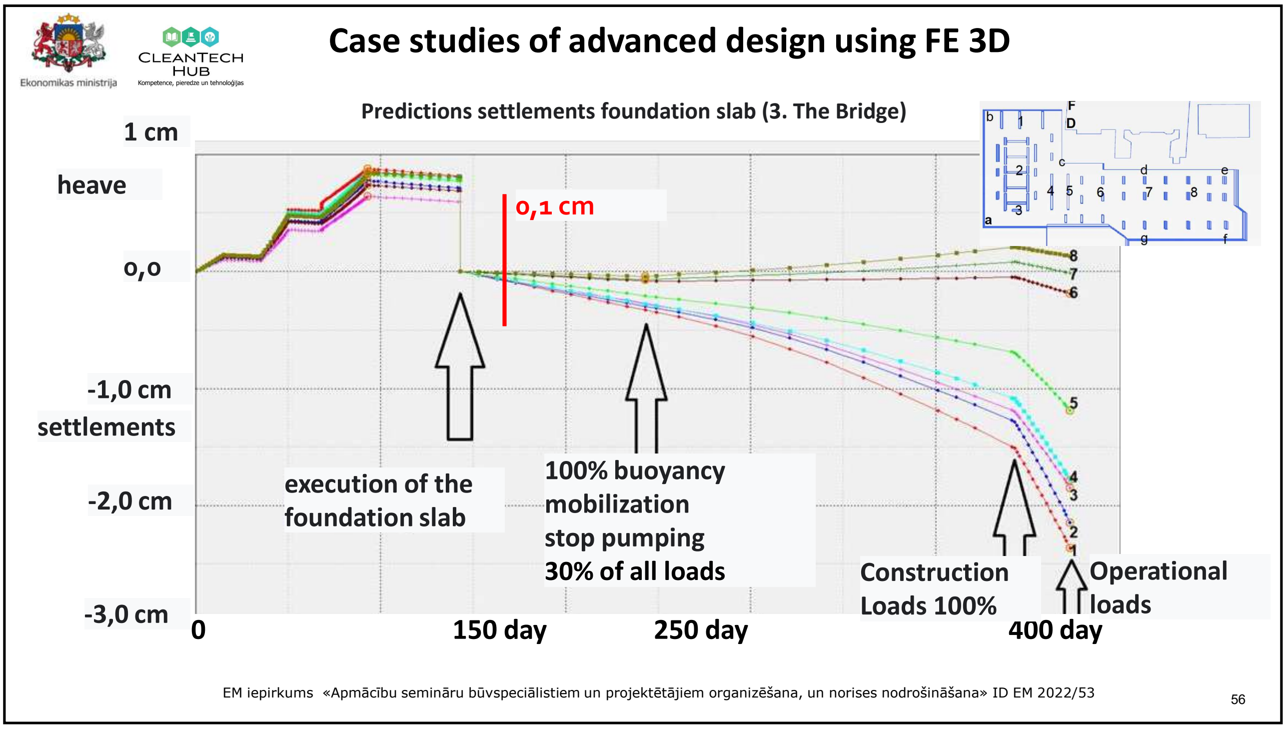
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Case studies of advanced design using FE 3D
Predictions settlements foundation slab (3. The Bridge)
1 cm
heave
0,0
-1,0 cm
settlements
-2,0 cm
-3,0 cm
0,1 cm
execution of the foundation slab
100% buoyancy mobilization
stop pumping
30% of all loads
Construction Loads 100%
Operational loads
0
150 day
250 day
400 day
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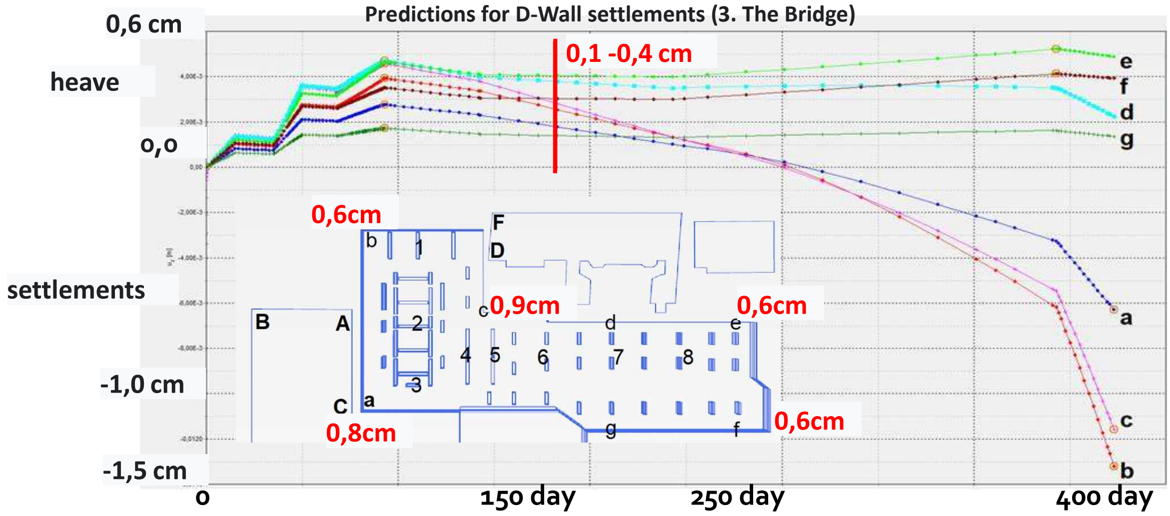

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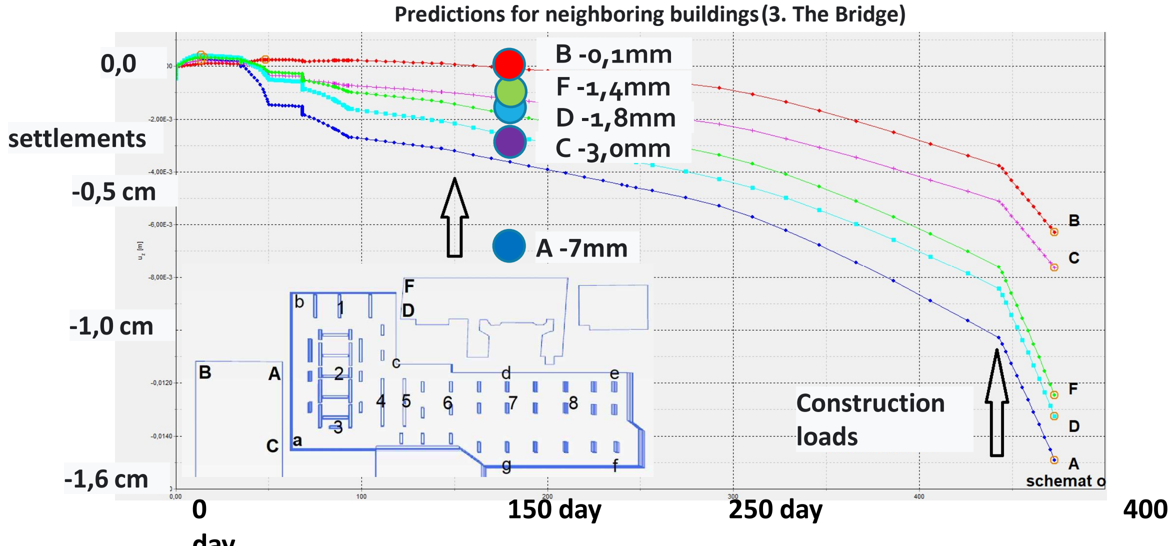

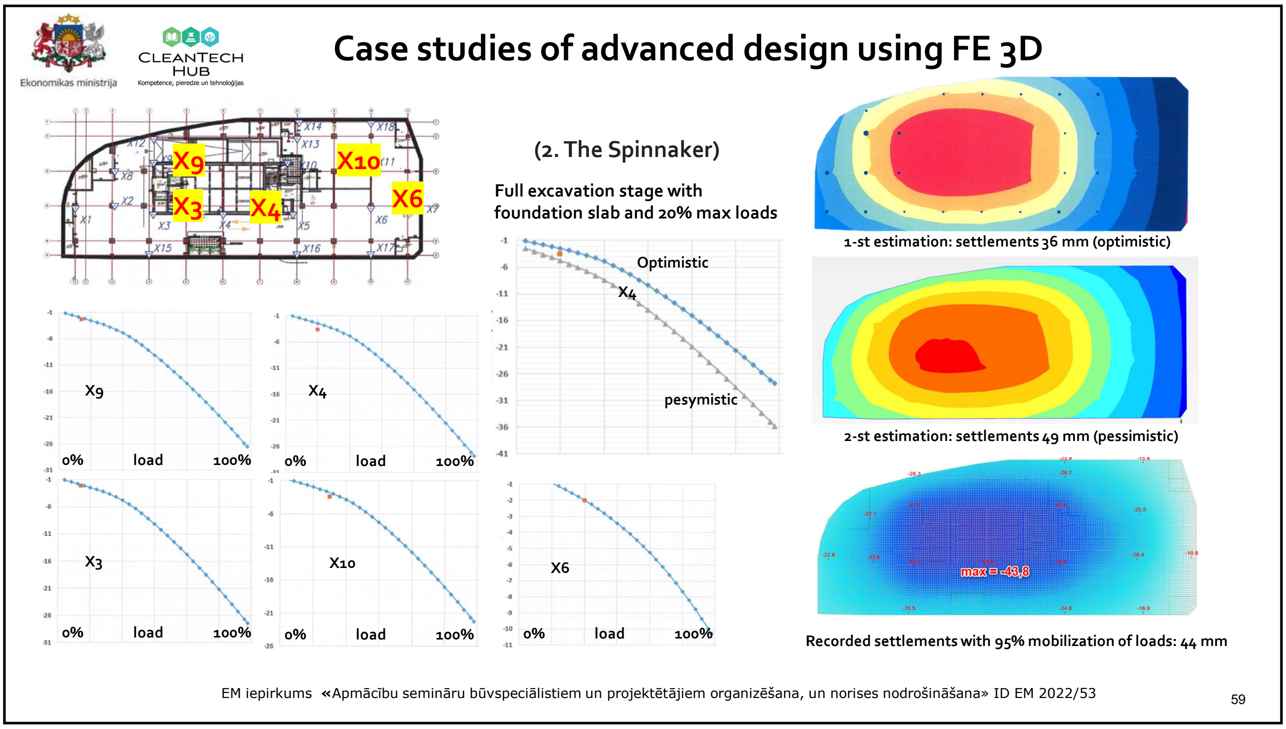
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Case studies of advanced design using FE 3D
X9
X10
X6
X3
X4
(2. The Spinnaker)
Full excavation stage with foundation slab and 20% max loads
Optimistic
X4
pesymistic
1-st estimation: settlements 36 mm (optimistic)
2-st estimation: settlements 49 mm (pessimistic)
max = -43,8
Recorded settlements with 95% mobilization of loads: 44 mm
X9
X4
X3
X10
X6
0%
load
100%
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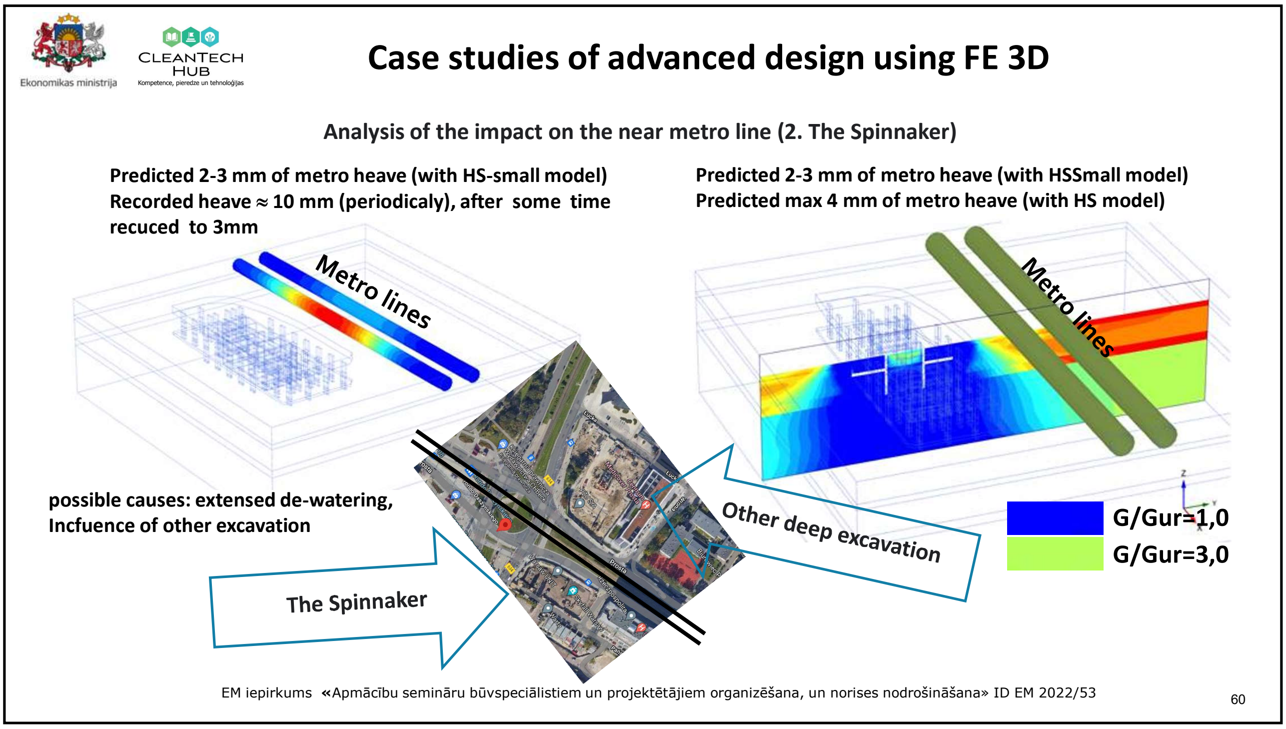
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Case studies of advanced design using FE 3D
Analysis of the impact on the near metro line (2. The Spinnaker)
Predicted 2-3 mm of metro heave (with HS-small model)
Recorded heave ≈ 10 mm (periodicaly), after some time recuced to 3mm
Predicted 2-3 mm of metro heave (with HSSmall model)
Predicted max 4 mm of metro heave (with HS model)
Metro lines
Metro lines
possible causes: extensed de-watering, Incfuence of other excavation
Other deep excavation
The Spinnaker
G/Gur=1,0
G/Gur=3,0
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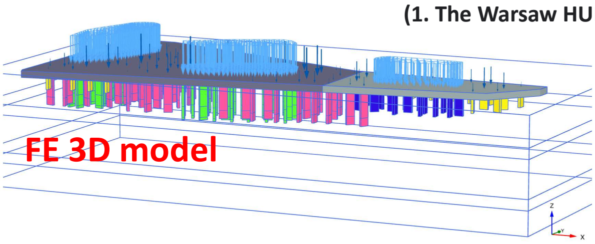
Case studies of advanced design using FE 3D

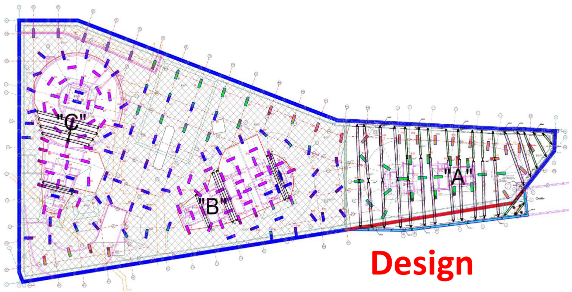
(1. The Warsaw HUB)



FE 3D model

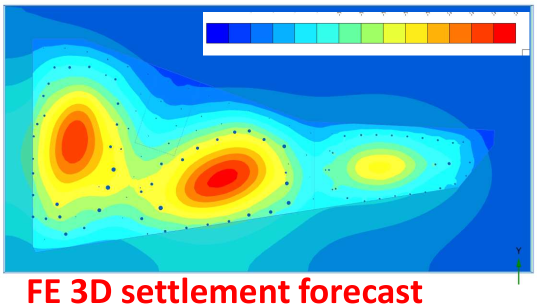
FE 3D model includes:

- Foundation slab
- Barrettes from 5m to 14m
- D-wall



Design

0 mm 26mm



FE 3D settlement forecast

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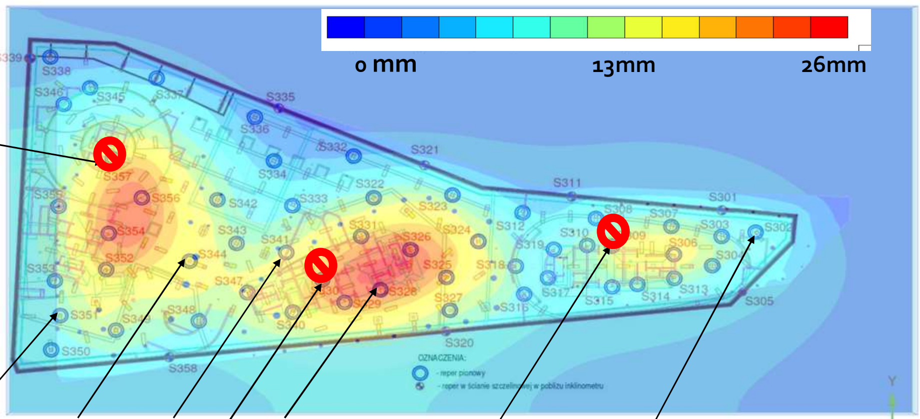
Case studies of advanced design using FE 3D

(1. The Warsaw HUB)

Max settlements from FE3D 24,8mm Max recorded settlements 21,1mm* +2-3mm



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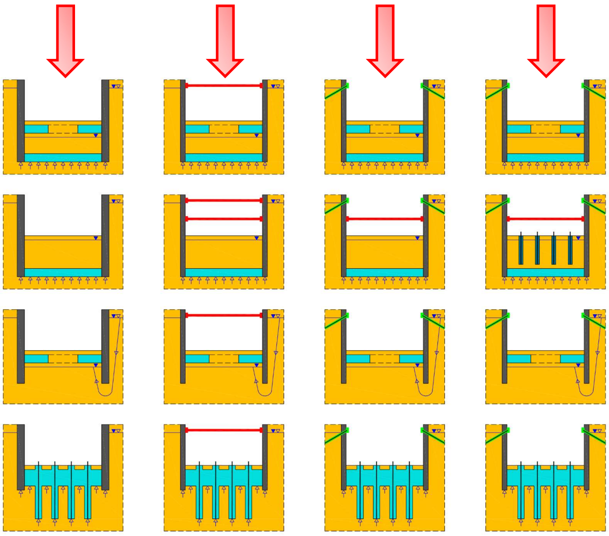
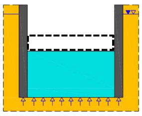
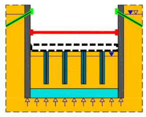
Lessons learned

STEP 1: Groundwater control | STEP 2: Wall support | STEP 3: Other issues





BASE DESIGN:
- solution: groundwater cut-off + wall support
- techniques: D-walls + Jet Grouting
- risk factor: low



ALTERNATIVE DESIGN:
- solution: groundwater cut-off + wall support + foundation slab anchoring
- techniques: D-walls + Jet Grouting + tiebacks (anchors) + steel struts + tiedowns (anchors)
- risk factor: low

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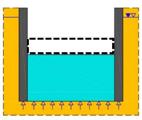
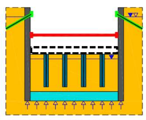
Lessons learned



BASE DESIGN:
- solution: groundwater cut-off + wall support
- techniques: D-walls + Jet Grouting
- risk factor: low

- Projects continue to increase in complexity
- Many different solutions have to be checked to find the best (most suitable) one
- All the design and execution aspects have to taken into consideration
- Use of FEM tools for design works is needed (with proper soil data and right experience)
- QA/QC of all works is very important
- Global and local experience is crucial



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Thank you for attention!

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Training seminar / Apmācību seminārs

Underpinning of Buildings and Compensation Grouting (Session 2)

Ēku pamatu pastiprināšana un kompensācijas cementācija (Sadaļa Nr.2)

Clemens Kummerer, PhD (Austria)

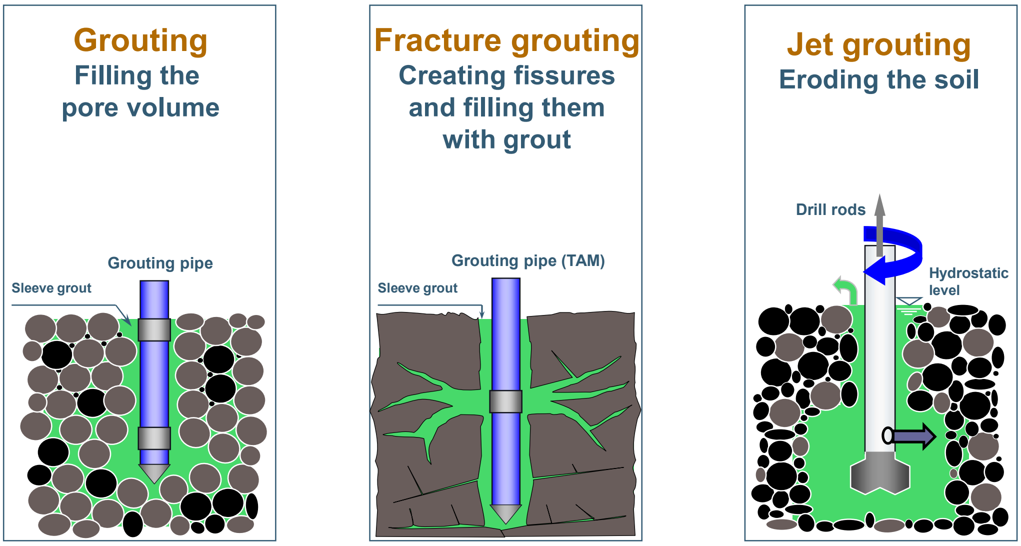
- Principles of jet and compensation grouting

General classification of ground improvement

- prEN 1997-3:202x: classification in clause 11

Class	Familiy	
	A-Diffused	B-Discrete
I	**AI – Diffused with no unconfined compressive strength** The improved ground has an increased shear strength or stiffness higher than that of the original ground. The improved ground can be modelled as a ground with improved properties **e.g. grouting methods**	**BI – Discrete with non-rigid inclusions** Inclusions, installed in the ground, with higher shear capacity and stiffness compared to the surrounding ground. The unconfined compressive strength of the inclusion is not measurable
II	**AII – Ground improvement zone with unconfined compressive strength** The improved ground is modified from its original natural state, has a measurable unconfined compressive strength and is significantly stiffer than the surrounding ground. Usually, it comprises a composite of a binder and ground **e.g. (jet) grouting methods**	**BII – Discrete with rigid inclusions** Rigid inclusions, installed in the ground, with unconfined compressive strength significantly stiffer than the surrounding ground. The inclusions can be an engineered material such as timber, concrete/grout or steel or a composite of a binder and ground

Overview (jet) grouting processes



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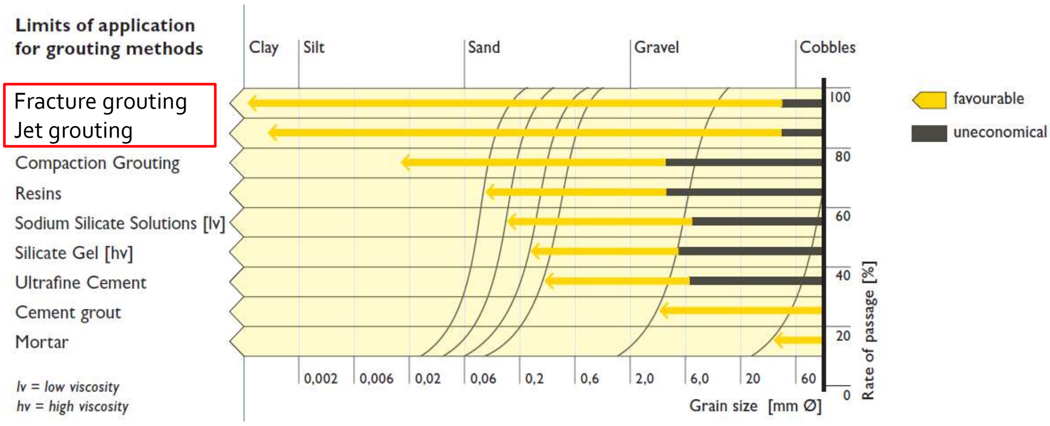
Grouting methods for various ground conditions



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The jet grouting process in detail

- Jet grouting is a process of **hydraulic disaggregation** of the soil or weak rock, which is achieved by a high energy jet of a fluid, which can be the **cementing agent** itself, and its concurrent mixing with, and partial replacement by grout, to create a jet grouted element after hardening of the hydraulic binder

  (EN 12716:2019)

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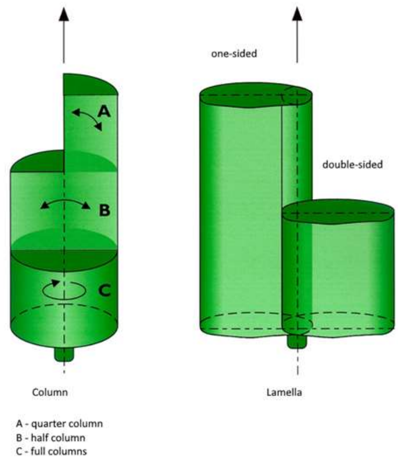
Jet grouting elements

- By controlling the movement of the monitor and the production parameters, different geometries can be produced
  - Full columns – circular or elliptical
  - Segments
  - Lamellas



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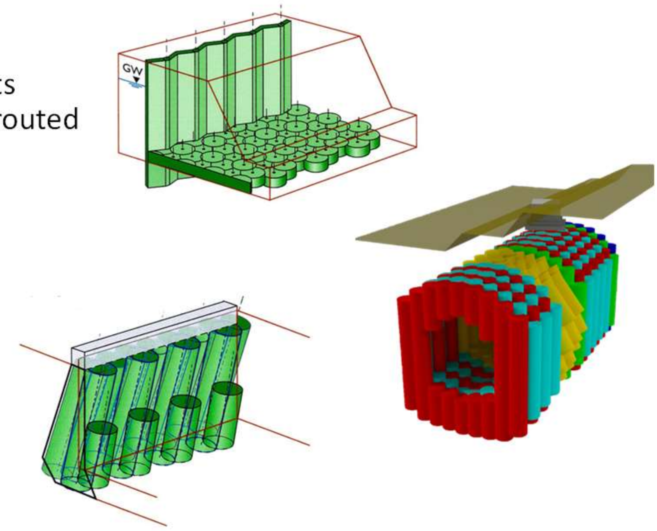
Jet grouting geometries

- By combining single elements complex geometries of jet grouted ground can be realized
  - Sealing slabs
  - Cut-off walls
  - Underpinning walls
  - Arches



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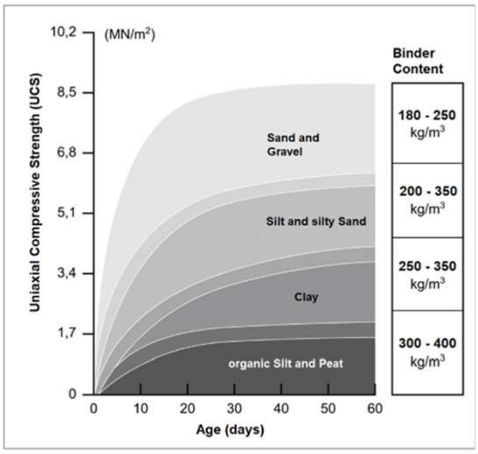
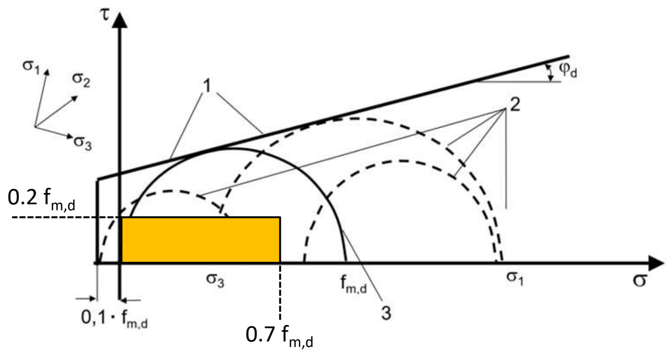
JG strength and simplified verification of stresses

- Indicative UCS-values



- Stress verification acc. to DIN 4093



Note: $f_{m,d}$ is design compressive strength (cylinder)

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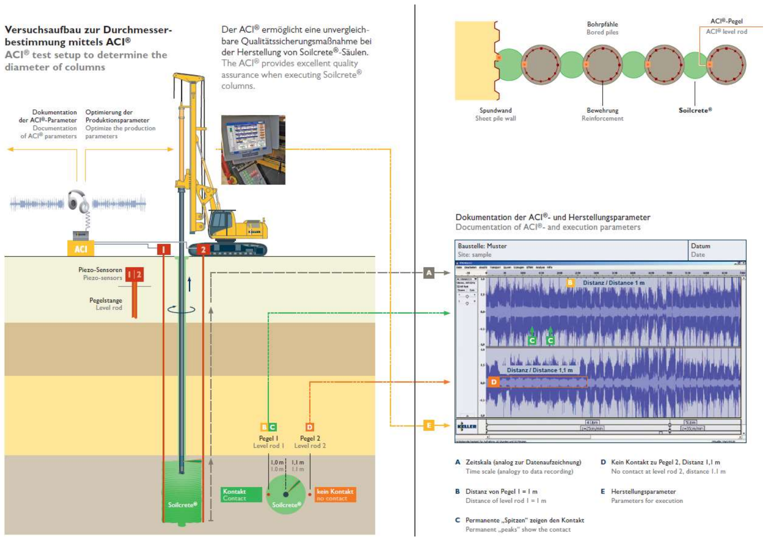
Quality control

Methods to determine the diameter during execution

- Various systems are available to monitor or measure the diameter
- One particular method is the ACI® (Acoustic Column Inspector) method where an acoustic signal at an installed rod is utilized to monitor the jet radius



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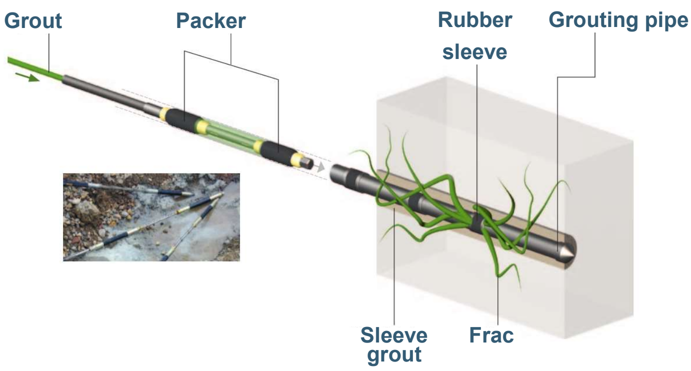
The fracture grouting process in detail

- Injection of grout that creates a new **localized fracture** in the ground (EN 12715:2021)
- In general hydraulic fracturing is used for compensation grouting



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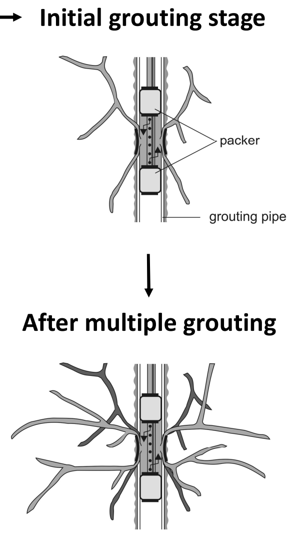
The classification of grouting

- Grouting principles
  - without ground displacement
    - Penetration grouting
      - Permeation grouting
      - Fissure / contact grouting
    - Bulk filling
  - with ground displacement
    - Compaction grouting
    - **Compensation grouting / hydraulic fracturing**

(Source: EN 12715)



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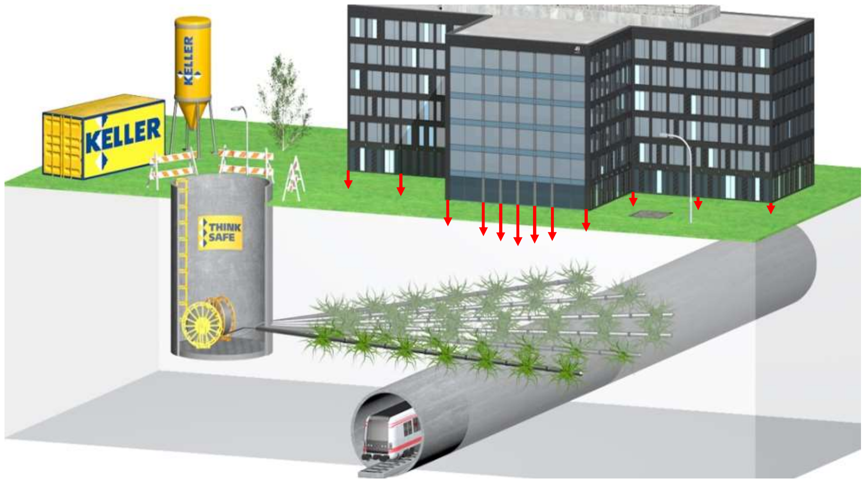
The concept of compensation grouting

- The objective of compensation grouting is to inject grout into the ground **undergoing volume loss** caused by
  - deep excavations
  - tunnelling
  - any other deformation feature



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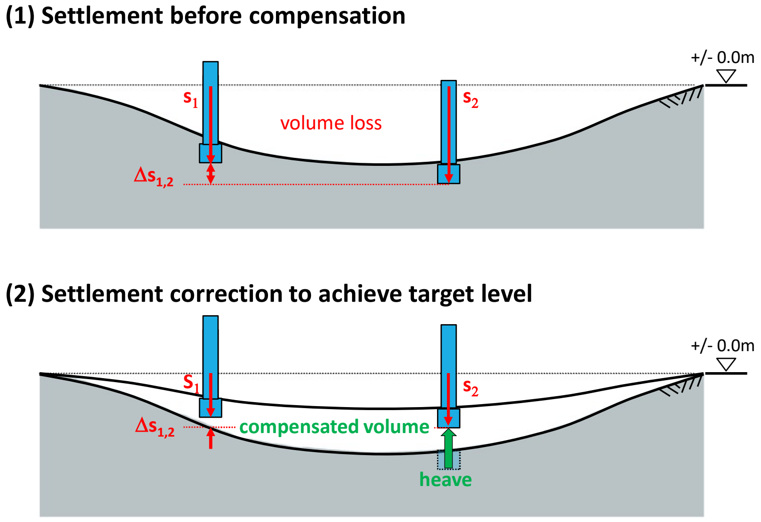
The concept of compensation grouting

- Compensation grouting is mainly a volume-driven problem
- For the design the volume loss and the influence zone need to be assessed
- The structural engineer has to specify the target heave and tolerances
- The 'lost volume' is compensated considering a grout efficiency factor



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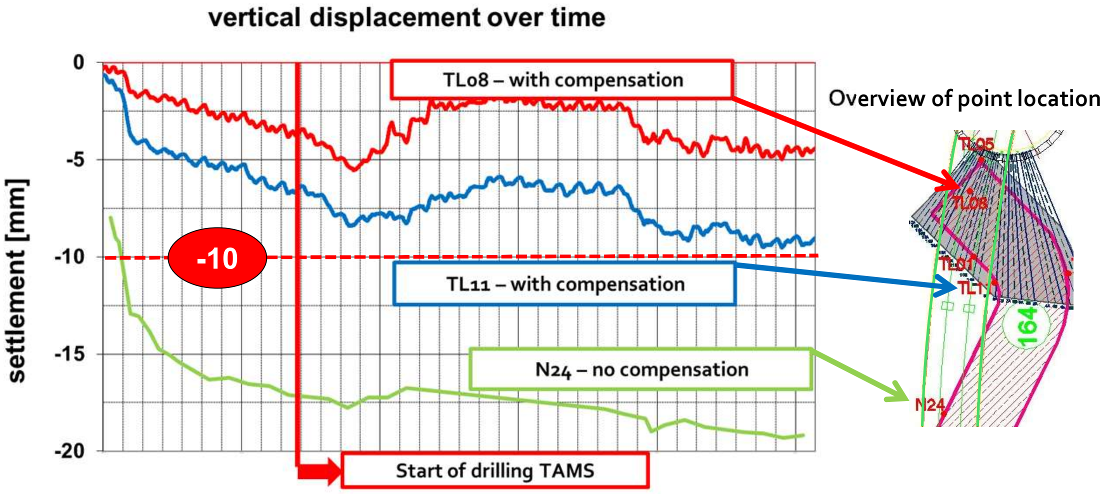
Prove of effectiveness of compensation grouting



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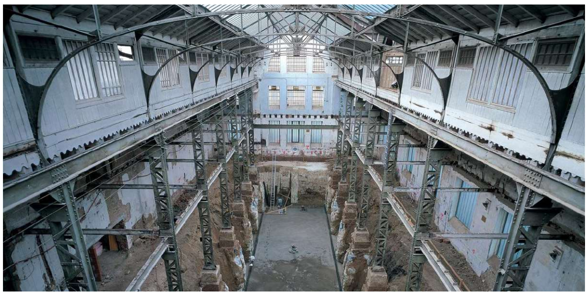
- Creating space below existing buildings

General considerations

- Creating space below existing buildings requires a comprehensive knowledge of the structure and sound planning (drawings!)
- Generally multiple stress distributions occur
- A tight coordination between the structural and geotechnical engineer is fundamental



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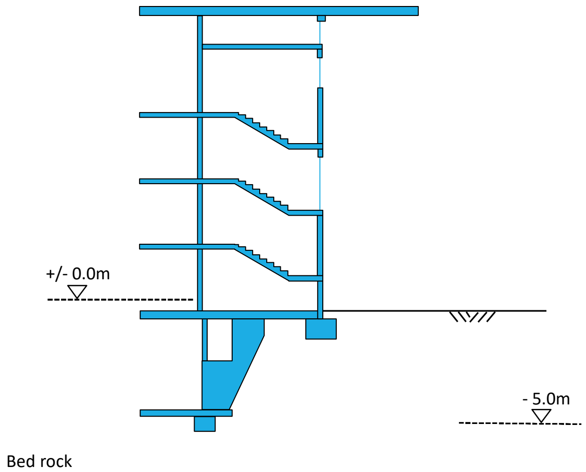
Construction of basement below existing building



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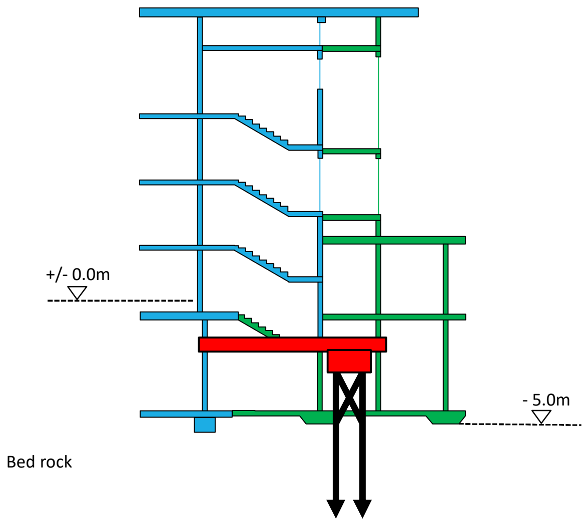
Stilted building supported by steel structure



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Construction sequence

- (1) Micropile type GEWI 63.5mm with steel tube 139.7mm in top section
- (2) Partial excavation step
- (3) Installation of pile head plates
- (4) Concrete blocks

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Construction sequence (cont'd)

- (5) Execution of supporting beams on different levels
- (6) Partial excavation step
- (7) Welding of steel plates to create a stiffening structure
- (8) Final excavation step

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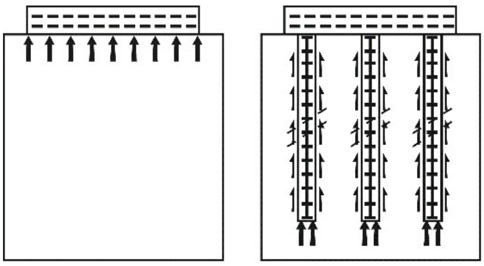
- Protecting deep foundations

General considerations

- Protecting deep foundations requires special attentions!
- The load bearing mechanisms (end bearing or friction) needs to be understood
- No undue impact (e.g. lateral forces) must affect the existing foundation elements



Raft Foundation | Pile Foundation

Rehabilitation of a deep bridge foundation

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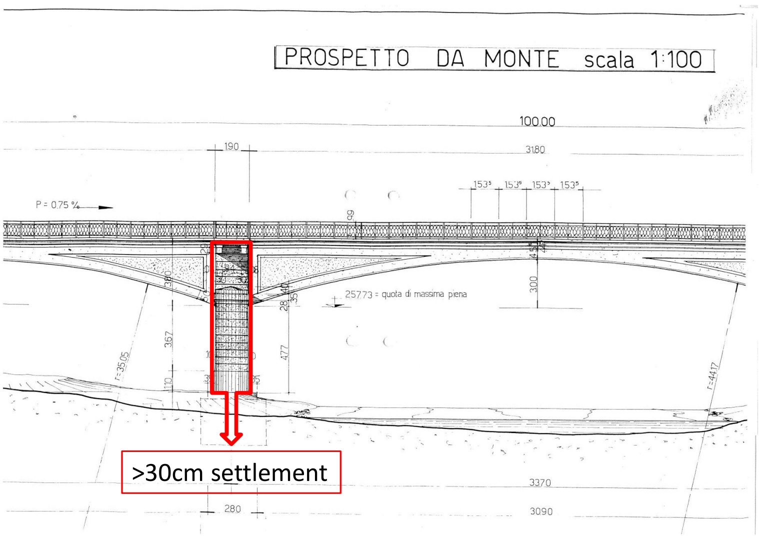
Rehabilitation of a deep bridge foundation

Problem statement

- Drillings were performed next to the bridge pier
- Due to artesian conditions large quantities of soil were fhlushed out of the ground
- The pier settled more than 30cm
- A plastic hinge formed in the reinforced concrete arch with 34m span



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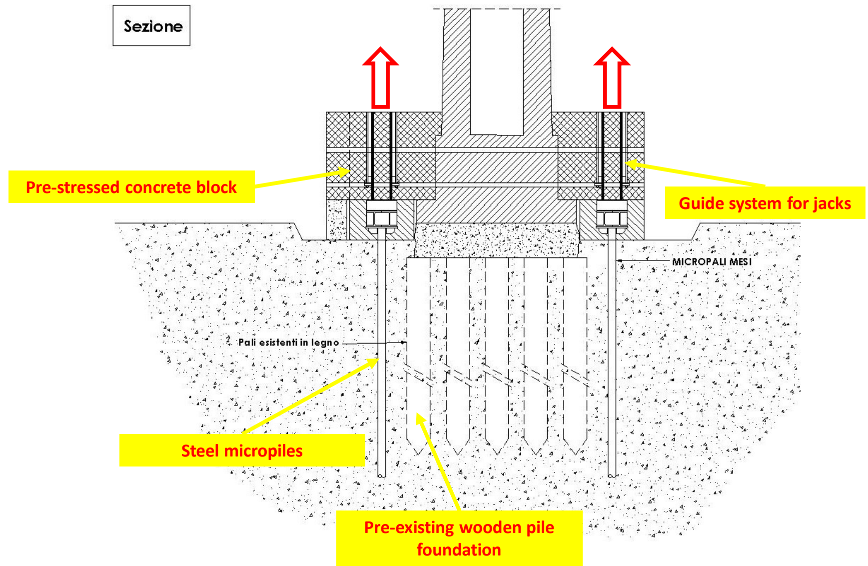
Rehabilitation of a deep bridge foundation

Concept for re-levelling of pier



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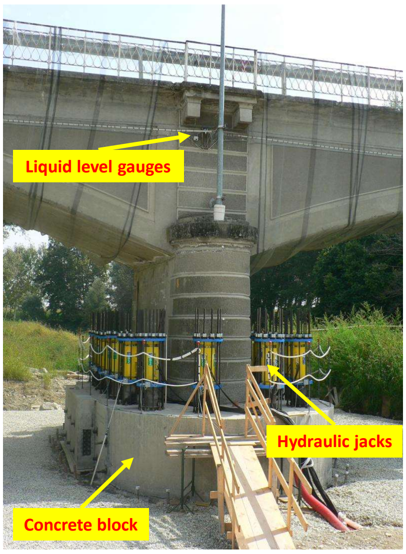
Rehabilitation of a deep bridge foundation

Execution steps

- Drilling of no. 48 micropiles system MESI, length 12m
- Realization of pre-stressed concrete blocks
- Installation of no. 20 hydraulic jacks
- Lifting of pier in 3 steps with 12cm each



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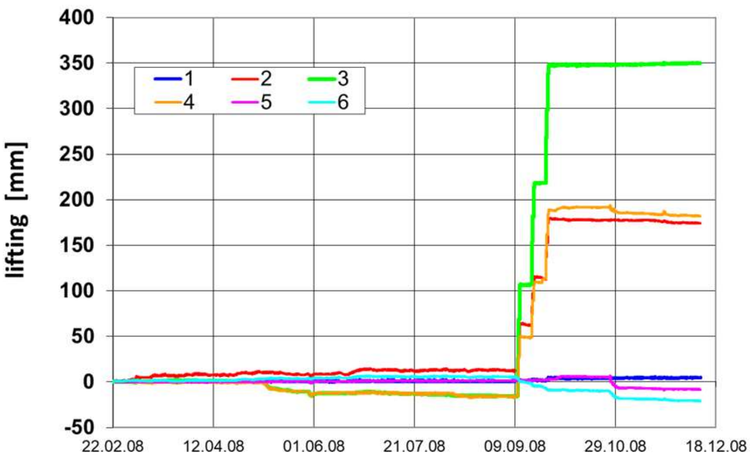
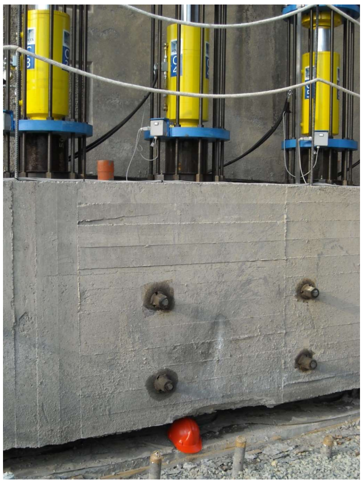
Rehabilitation of a deep bridge foundation
Lifting with hydraulic jacks

- Lifting history



- Detail



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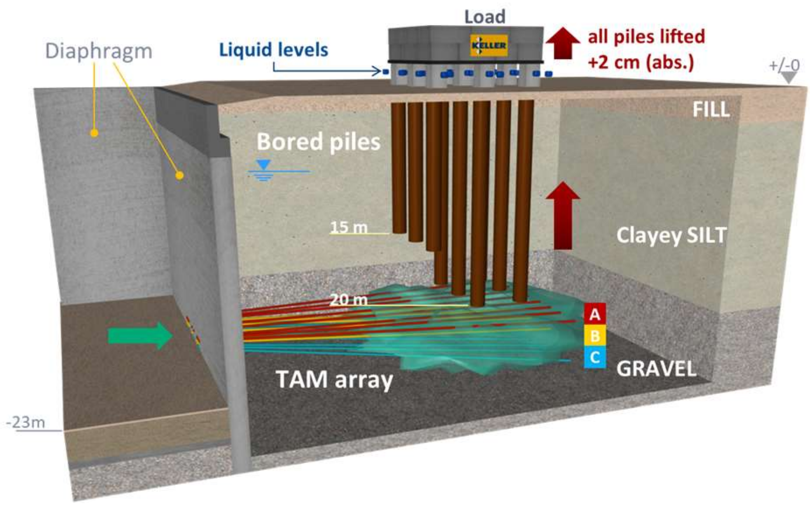
Compensation grouting for protecting pile foundations

- For geometric reasons drilling beneath piles is a complex task
- For circumstances with limited experience it is generally advisable to conduct a field test
  - E.g. heavily loaded piles or different pile length



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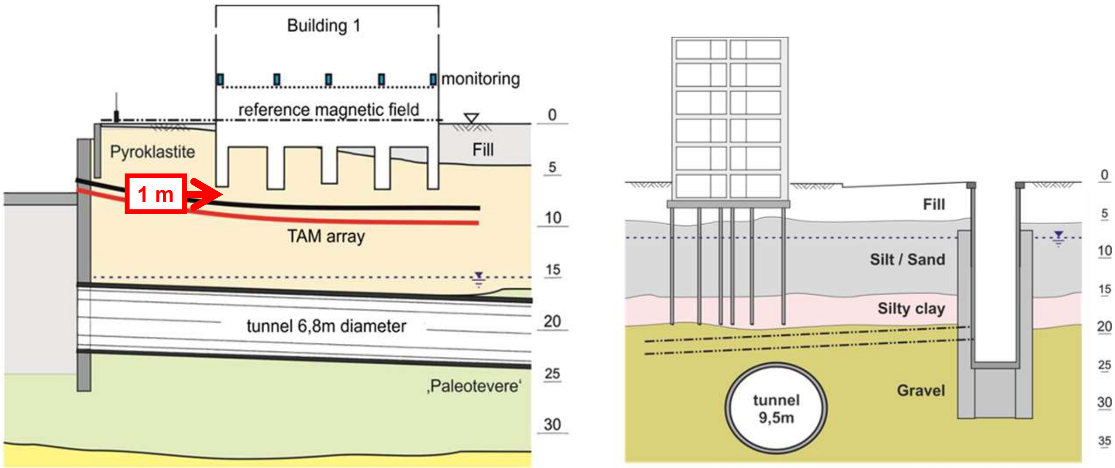
Protection of deep foundations from excavation induced settlement



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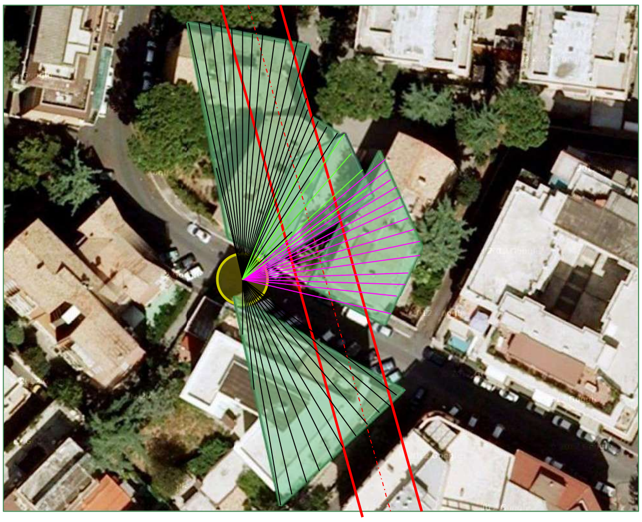
Performance of compensation grouting with piled foundations

- In densely built-up areas it requires special solutions to find space for drilling locations, e.g. shafts
- A monitoring system shall be in place prior to drilling
- The drilling method needs to be minimal invasive to avoid disturbing the soil



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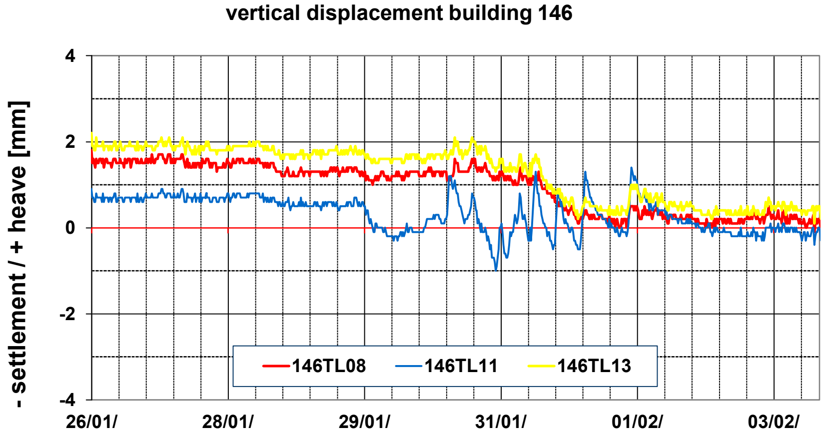
Performance of compensation grouting with piled foundations



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- Underpinning of historical buildings

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General considerations for projects in urban environment

- Limited space in and around buildings to establish work areas (especially inside buildings)
- Archaeological findings
- Risk of presence of UXO (unexploded ordonnance)
- Adjacent buildings in influence area with sometimes limited documentation on existing foundation (vaults!)
- Underground services from cables to underground lines
- Artificial fills / man made ground

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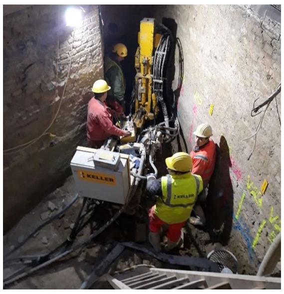
Comparison manual vs. jet grouted underpinning

Method	Pro	Con
Manual with concrete or shotcrete	• Very limited site installation • Economic for small projects	• Limited in depth, with ground water, loads • Time consuming • Use of neighbouring property with nails
Jet grouting	• Very flexible method • Direct connection to foundation • Taylor-made equipment available	• Site installation for very small projects



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Comparison manual vs. jet grouted underpinning

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Options for underpinning / excavating limiting deformation

Option diaphragm wall / bored piles

- Access to site limited
- Loss of volume as installation only in front of the wall

Option Jet grouting

- Easy access
- Direct underpinning possible

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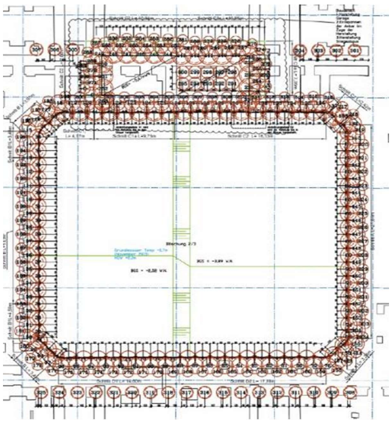
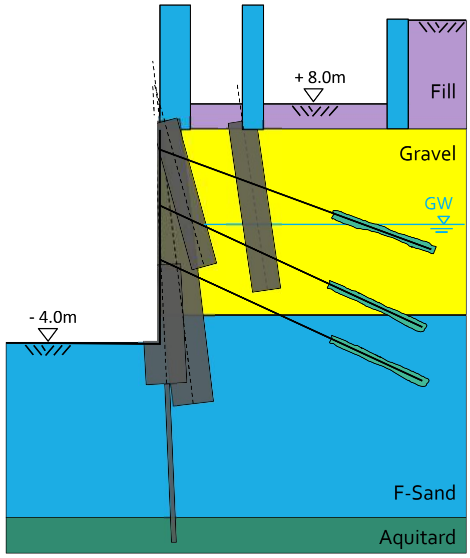
Proven underpinning solution with tied-back jet grouting





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- Monitoring of settlements and deformations

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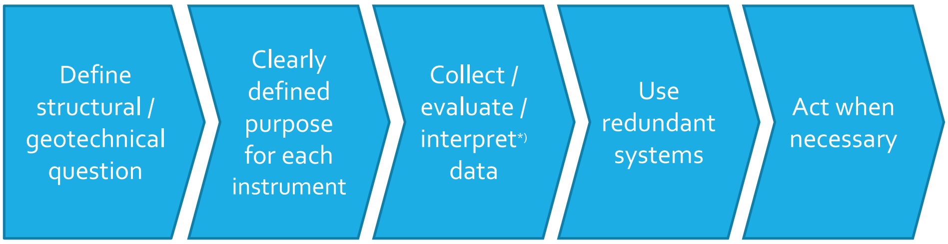
Monitoring systems – general considerations

- Value of monitoring is improving safety, reducing risk and saving time & budget



*) Interpretation: Meaning of data; cause and effect; implications

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Observational method

- Introduced by Terzaghi as ‚learn as we go‘
- Also referred to as ‚interactive geotechnical design‘
- Concept established in EC 7
- Applied when the prediction of geotechnical behaviour is difficult > the design needs to be reviewed during construction:
  - Establish acceptable limits of behaviour
  - Have a monitoring plan
  - Devise a contingency plan

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Widely used structural monitoring technologies

- Automated Total Stations

- Autonomous optical monitoring
- High precision
- Frequent readings
- Monitoring of settlement and deformation
- Requires installation of prisms and a robotic station with direct line of sight
- No cable connection

- Liquid Levelling System

- Settlement monitoring
- Very high precision
- Real time monitoring
- Requires installation of hydrostatic levelling cells
- Physical connection between cells necessary

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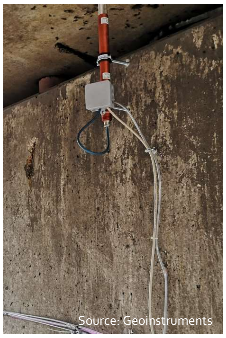
Widely used structural monitoring technologies

- LVDT transducers



- Monitors linear displacements
- Utilized to monitor relative displacements between structures or cracks
- Easy installation

- Tiltmeters

- Tracks twist and cant deformation
- Applied on facades or individual structural elements
- Easy installation

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Widely used geotechnical instrumentation

Method	Typical application
Inclinometers	Measurement of deformation of diaphragm walls or bored pile
Shape Arrays SAA	Permanent or temporary installation of SAA in piles etc.
Fibre Optic Sensing	Monitoring of deformation /strain in load bearing elements
Extensometers	Measuring differential deformation between distinct points in the ground
Piezometers	Observing water pressure and excess porewater pressure changes

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- Case studies of advanced application
- Lessons learned from challenging projects

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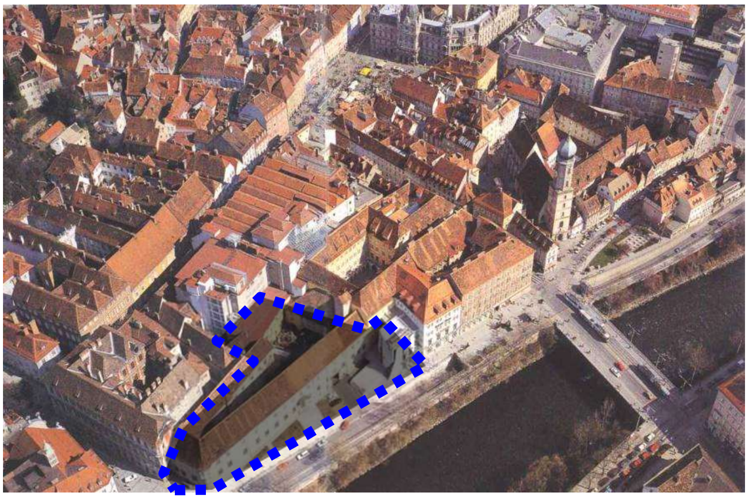
Underground car park underneath a historic building

- Realization of an underground car park in the city centre of Graz, Austria
- No. +500 parking lots on 5 underground levels beneath the listed 'Admonter Hof'
- Excavation of max. 18m, with 11m below groundwater level



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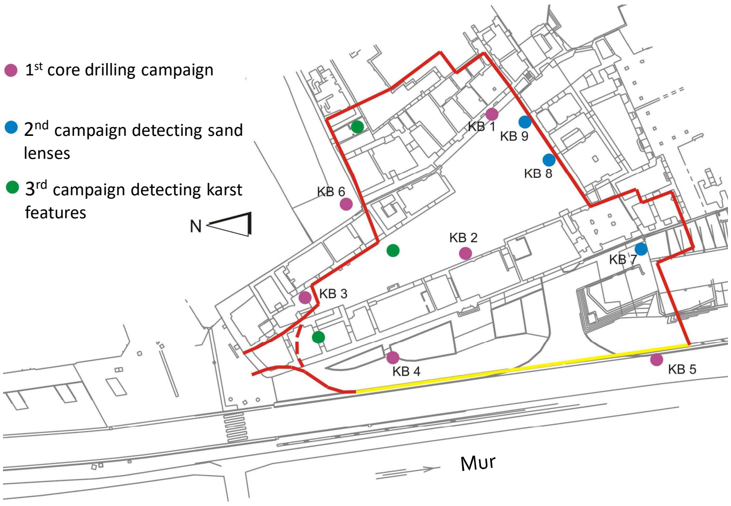
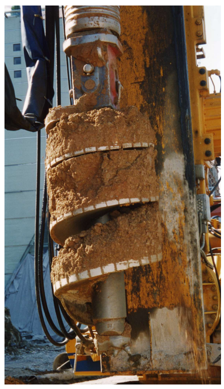
Underground car park underneath a historic building
Site layout with ground investigation



Quaternary gravel



Tertiary stiff to firm silt

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Underground car park underneath a historic building

Underpinning and supporting structure in plan view

- Buildings along the perimeter were underpinned by means of jet grouting and injection / shotcrete
- The central building 'Admonter Hof' was retained with concrete beams founded on bored piles / micro piles

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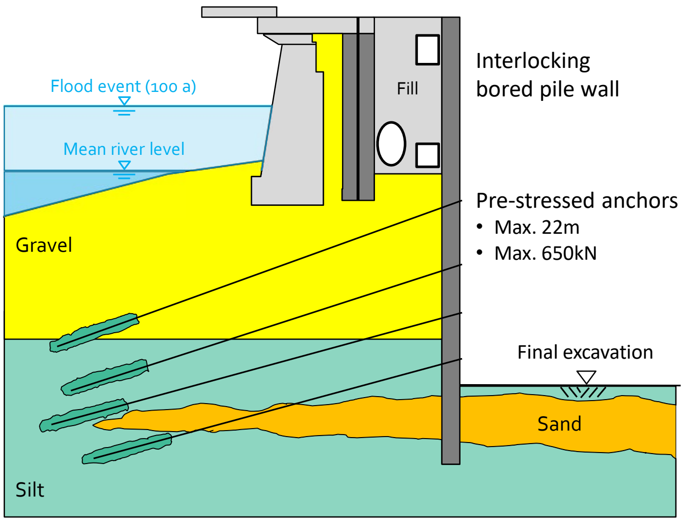
Underground car park underneath a historic building

Bored pile wall for excavation support



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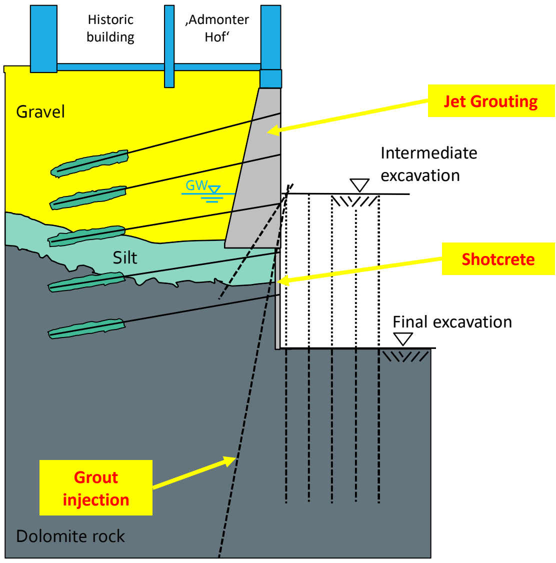
Underground car park underneath a historic building
Underpinning of adjacent buildings

- Underpinning of upper part in gravel layer with jet grouting
- Shotcrete wall to protect the silt layer and the transition to the underlying rock
- Tie-back system with multiple layers of pre-stressed anchors
- Grouting to strengthen the silt layer and to limit water ingress especially in dolomite rock



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Underground car park underneath a historic building
Underpinning of adjacent buildings

- Jet grouting with limited head room
- Jet grouting with standard rig
- Reinforced shotcrete wall

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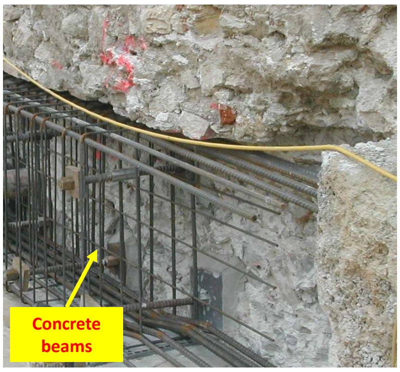
Underground car park underneath a historic building

Underpinning of main building

- Concreting of pile caps after drilling the bored piles
- Installation of concrete beam underneath strip footings



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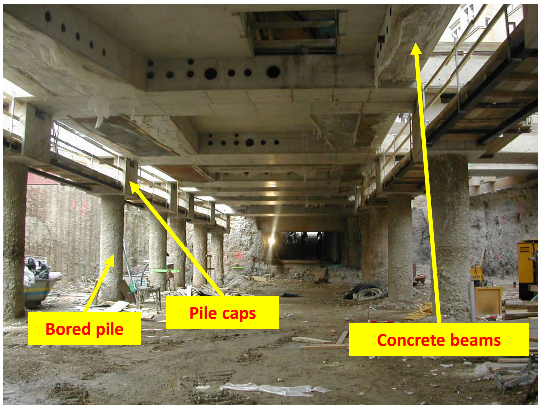
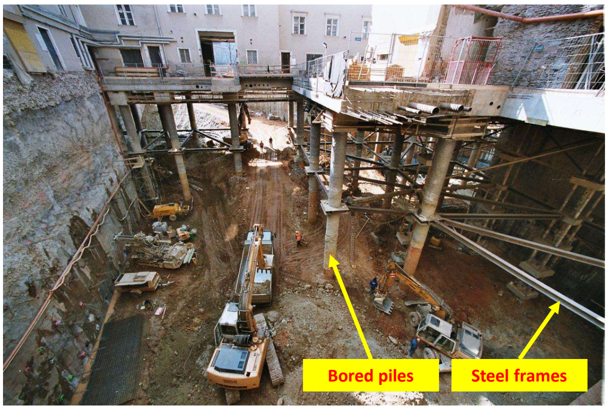
Underground car park underneath a historic building

Underpinning of main building

- 1st excavation phase above ground water level
- 2st excavation phase to final level after grouting campaign





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Underground car park underneath a historic building - Underpinning of main building

- The building deformation was monitored by means of a liquid levelling system
- No. 2 independent measurement circuits with no. 33 gauges in total were utilized

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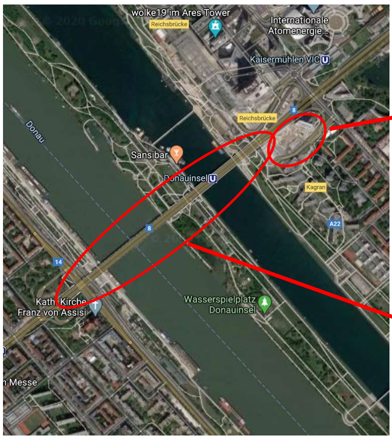
Compensation grouting to protect Danube river bridge



Danube flats

'Reichsbrücke' over Danube river

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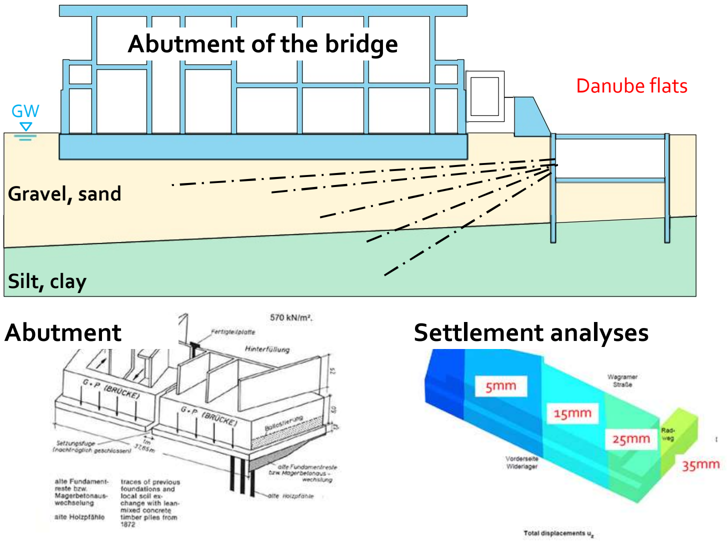
Compensation grouting to protect Danube river bridge
Cross section

- The bridge accommodates all kind of traffic (from pedestrian to underground line) and service lines
- The settlement calculation showed a significant differential settlement induced by the construction of the high-rising building



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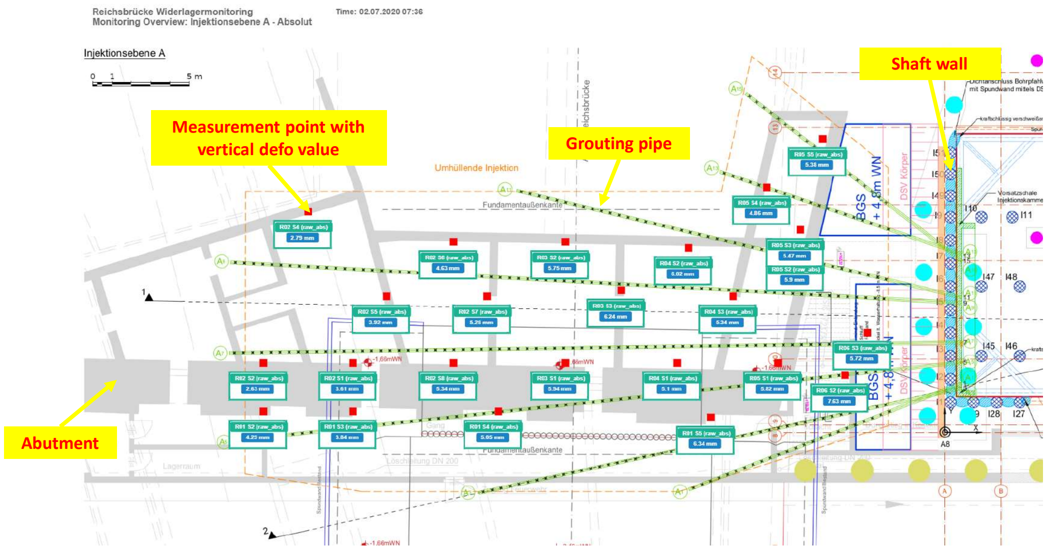
Compensation grouting to protect Danube river bridge
Grouting array in plan view



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

Compensation grouting to protect Danube river bridge
Pictures from execution

- Grouting from shaft made of piles and sheet piles
- Grouting pipes with preventer and grouting tubes

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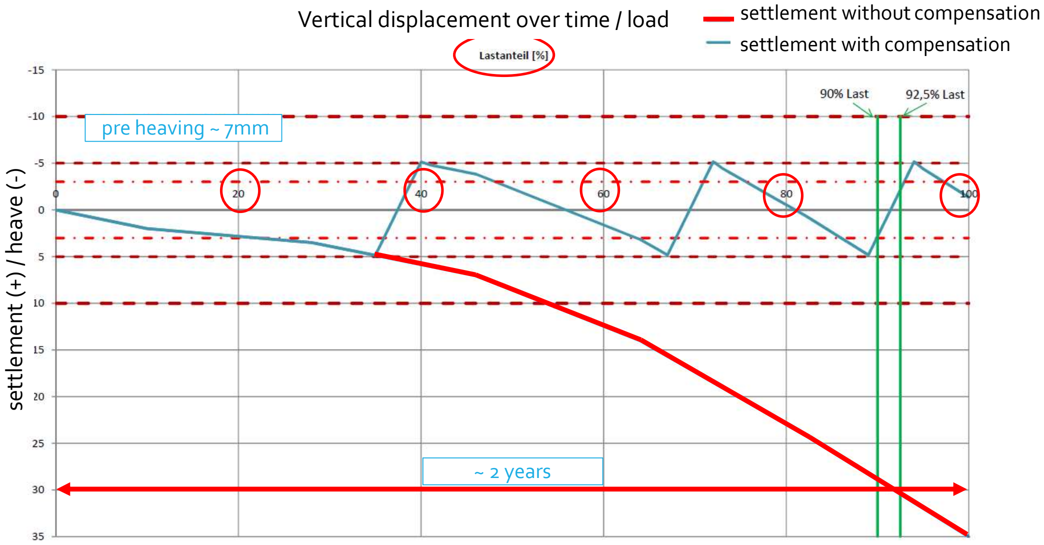
Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

Compensation grouting to protect Danube river bridge
Settlement / heave pattern



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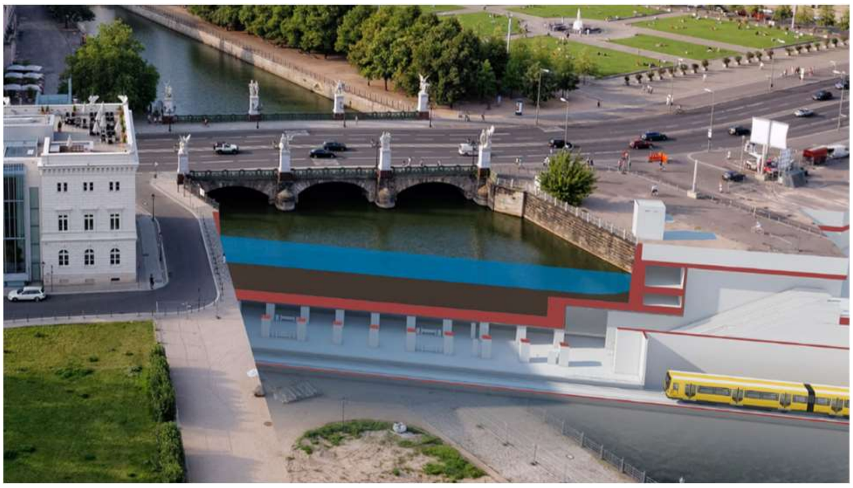
Compensation grouting for settlement compensation in Berlin

- Two tunnels with 5.7m diameter were excavated as part of the new underground line U5 in Berlin
- The new station ‘Museumsinsel’ was constructed next to /underneath the historic building ‘Bertelsmann’



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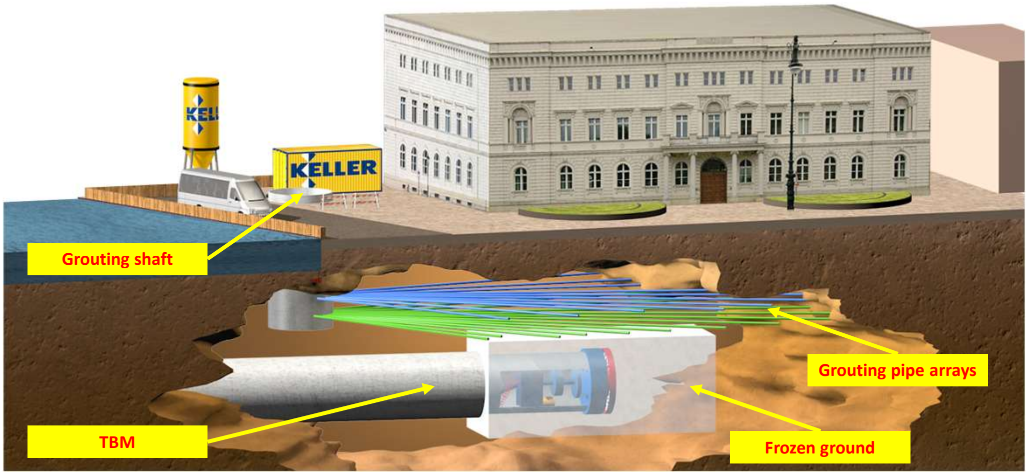
Compensation grouting U5 Berlin
General scheme



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Ekonomikas ministrija

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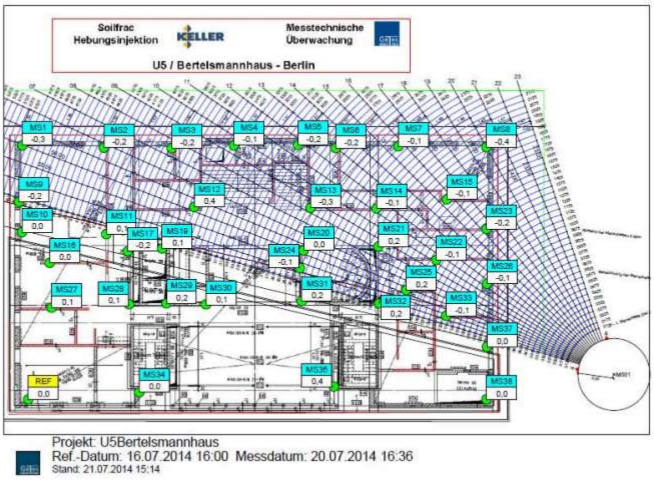
Compensation grouting U5 Berlin

Details

- A comprehensive deformation analysis highlighted that mitigation measures need to be implemented to prevent damages to the building
- A 10m deep shaft was realized
- No. 2 arrays of grouting pipes were installed (max. 55m long)
- No. 35 liquid levelling gauges formed the measurement system



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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Ekonomikas ministrija

CLEANTECH HUB Kompetence, pieredze un tehnoloģijas

Compensation grouting U5 Berlin

Pictures from execution

- Data from monitoring system and grouting were visualized in one software
- Alert and limit values were defined to establish the campus within the grouting works can be executed

EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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Lessons learned and conclusions

- Very challenging projects can be realized for creating new space in built-up areas
- A sufficient documentation of the buildings (structure, geometry, loads, foundation) in the influence zone is important to define the appropriate underpinning / protection method
- Projects will be successful when the structural and the geotechnical engineer closely work together and the contract reflects the complexity of the task
- A sound monitoring programme with expert interpretation needs to be in place
- The selection of the best suiting geotechnical measure should involve geotechnical contractors from an early stage

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Thanks you for your kind attention!

Questions & Answers

Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

Training seminar / Apmācību seminārs

The Use of Ground Improvement for Heavily Loaded Objects (Session 3)

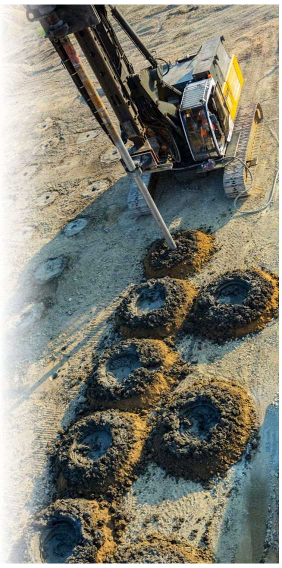
Grunts pastiprināšanas risinājumu izmantošana projektos ar lielām slodzēm uz pamatu konstrukcijām (Sadaļa Nr.3)

Prof. Michał Topolnicki, PhD (Poland)

Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

Scope of presentation

- Introduction
- Selected GI technologies
- Case studies illustrating the design and use of GI as an alternative to conventional piling
- Benefits of GI use
- Conclusions
- Q/A



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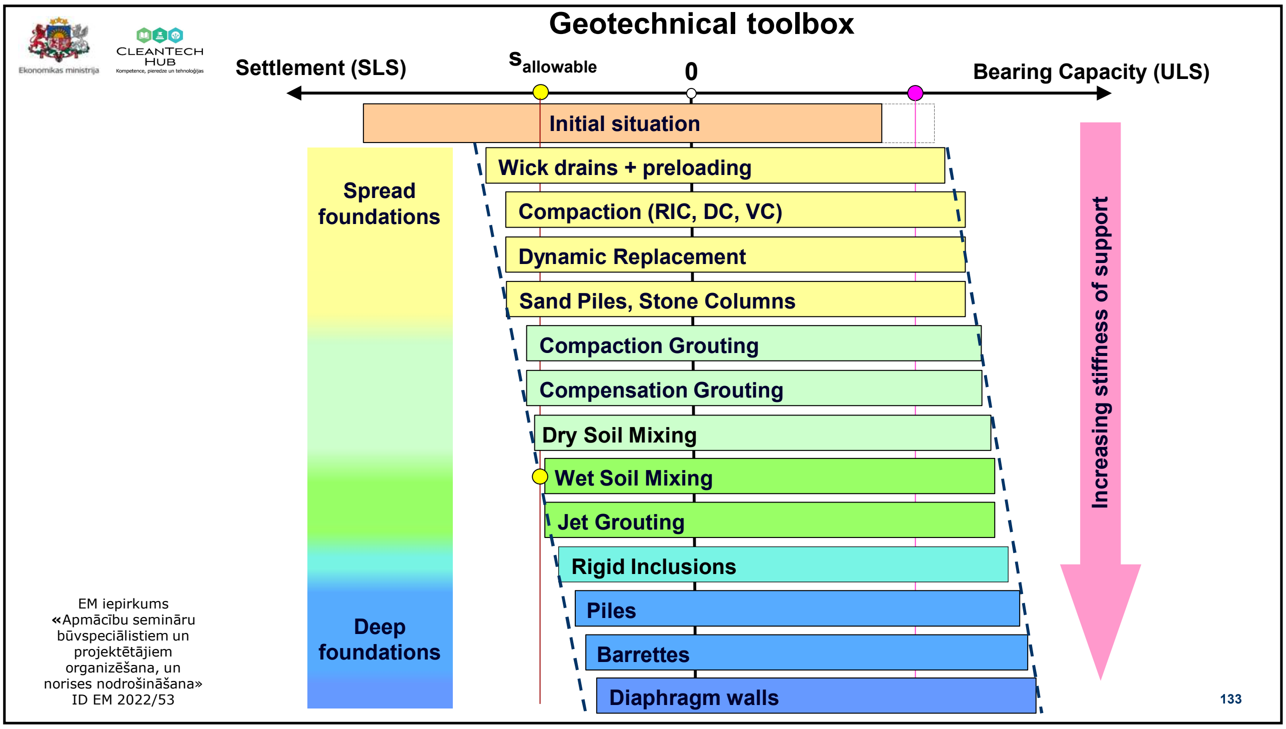
Geotechnical toolbox
Ekonomikas ministrija
CLEANTECH HUB
Settlement (SLS)
s allowable
0
Bearing Capacity (ULS)
Initial situation
Spread foundations
Deep foundations
Wick drains + preloading
Compaction (RIC, DC, VC)
Dynamic Replacement
Sand Piles, Stone Columns
Compaction Grouting
Compensation Grouting
Dry Soil Mixing
Wet Soil Mixing
Jet Grouting
Rigid Inclusions
Piles
Barrettes
Diaphragm walls
Increasing stiffness of support
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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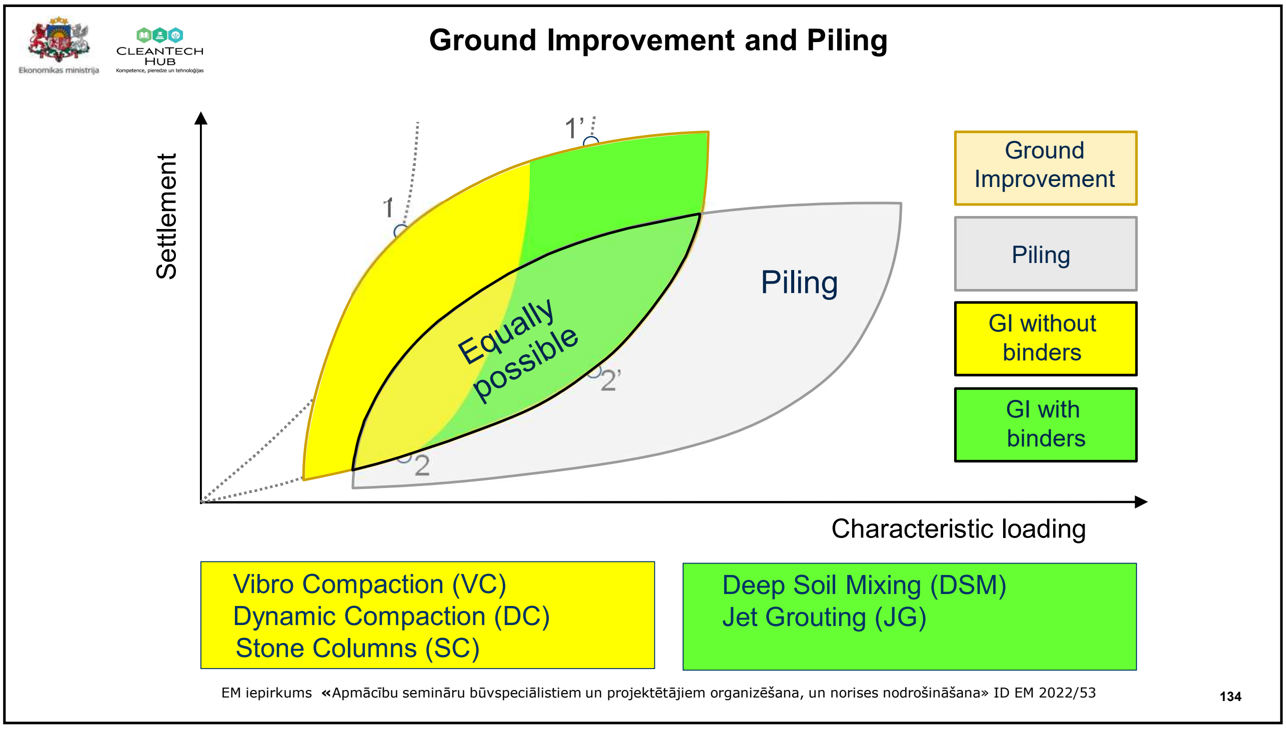
Ground Improvement and Piling
Ekonomikas ministrija
CLEANTECH HUB
Settlement
1
1'
2
2'
Equally possible
Piling
Characteristic loading
Ground Improvement
Piling
GI without binders
GI with binders
Vibro Compaction (VC)
Dynamic Compaction (DC)
Stone Columns (SC)
Deep Soil Mixing (DSM)
Jet Grouting (JG)
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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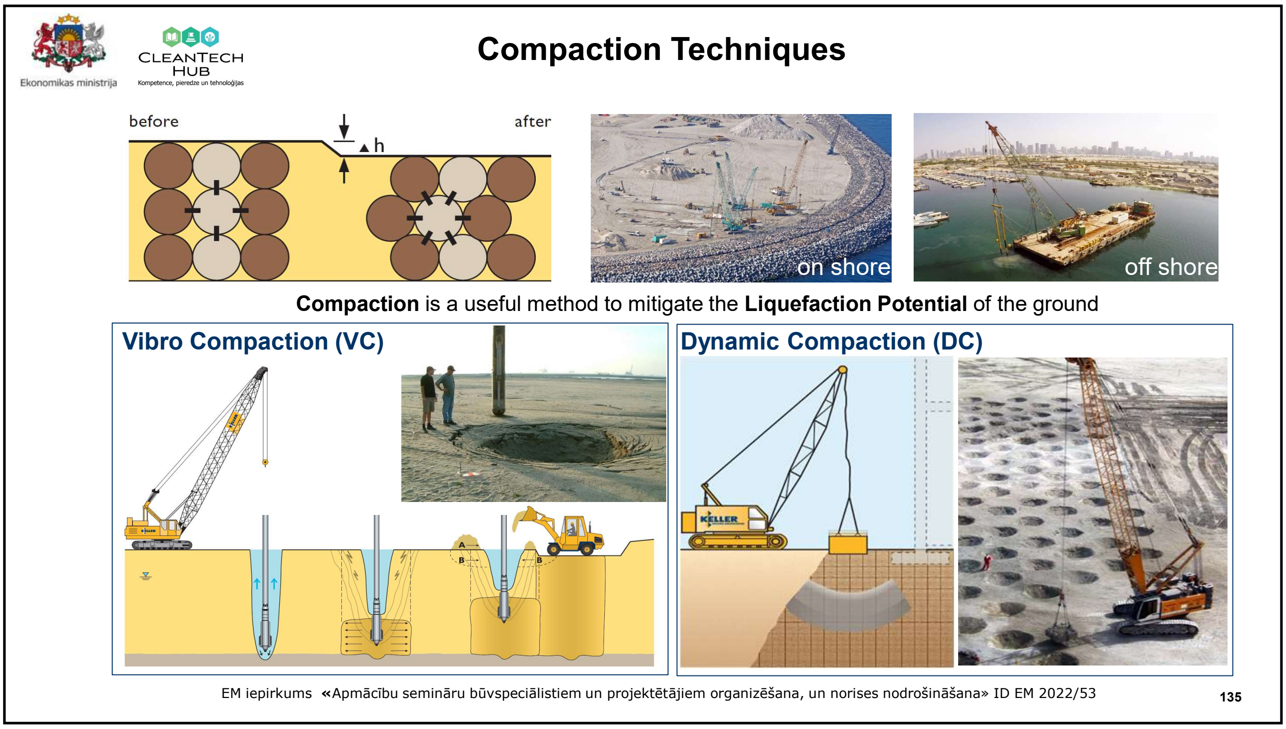
Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Compaction Techniques
before
after
h
on shore
off shore
Compaction is a useful method to mitigate the Liquefaction Potential of the ground
Vibro Compaction (VC)
Dynamic Compaction (DC)
KELLER
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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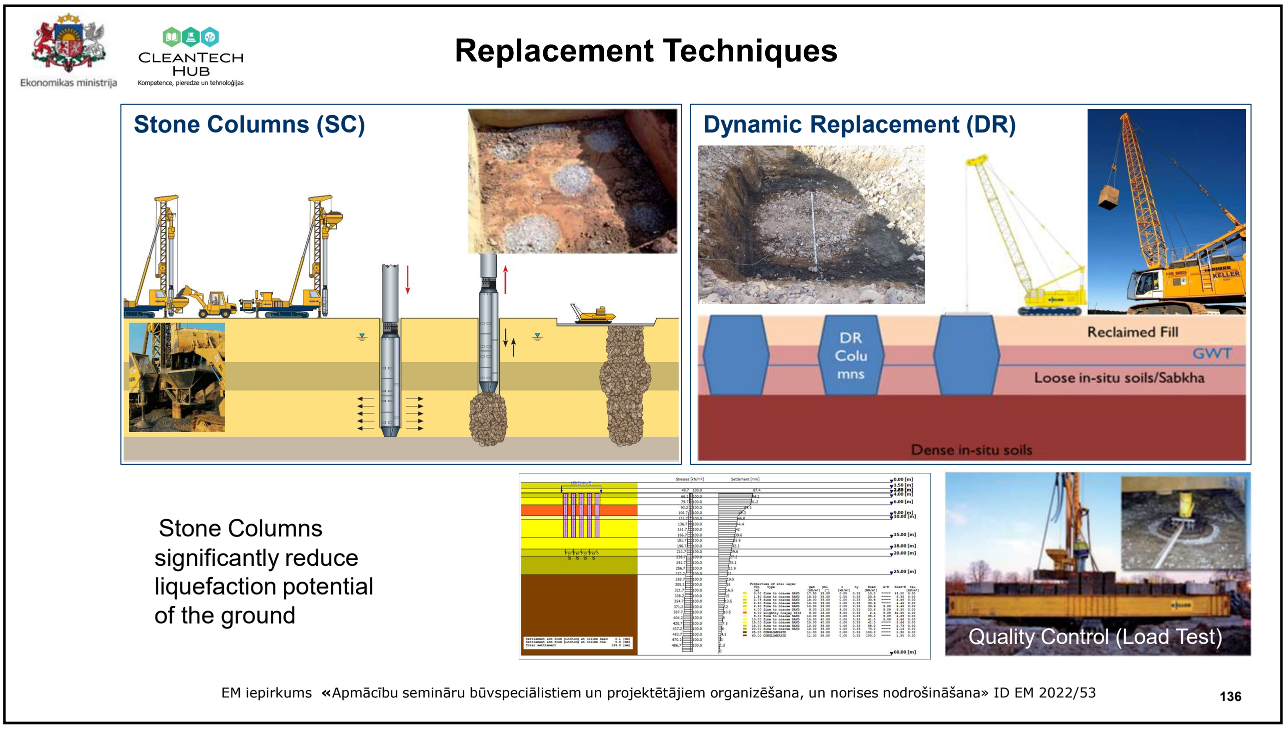
Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Replacement Techniques
Stone Columns (SC)
Dynamic Replacement (DR)
DR
Colu
mns
Reclaimed Fill
GWT
Loose in-situ soils/Sabkha
Dense in-situ soils
Stone Columns
significantly reduce
liquefaction potential
of the ground
Quality Control (Load Test)
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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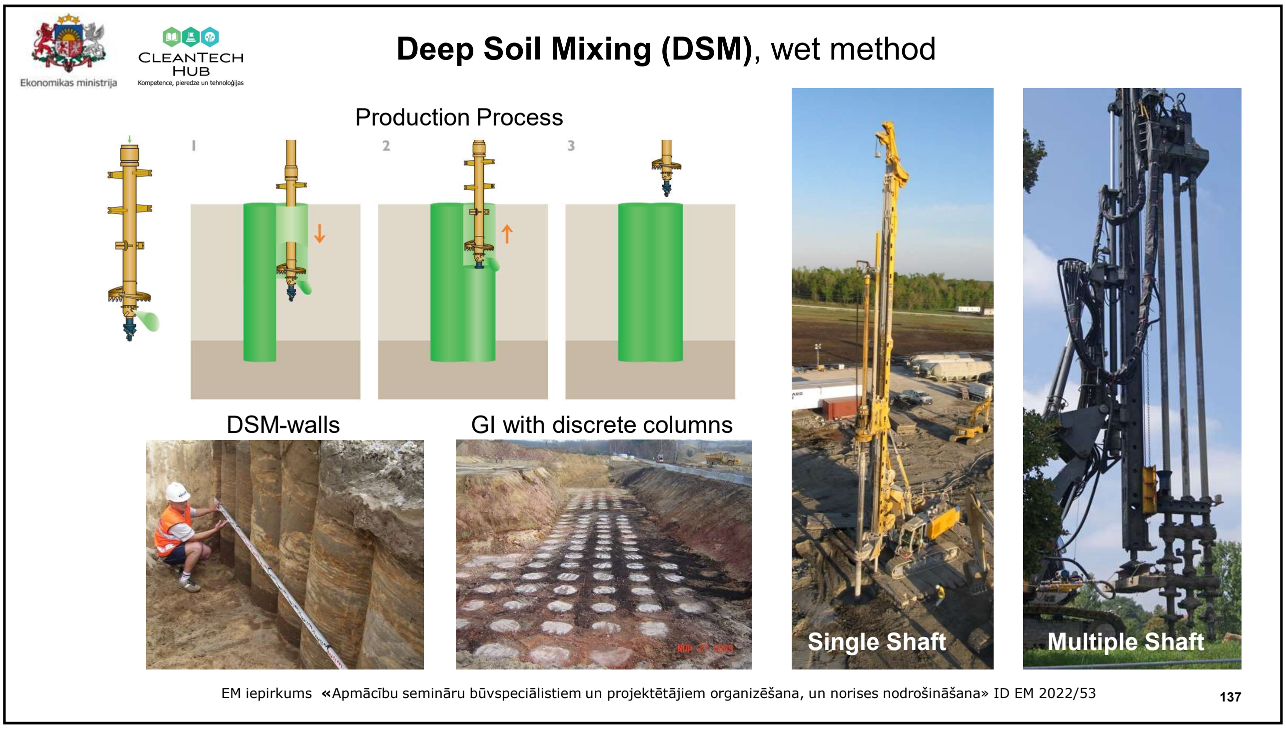
Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Deep Soil Mixing (DSM), wet method
Production Process
1
2
3
DSM-walls
GI with discrete columns
Single Shaft
Multiple Shaft
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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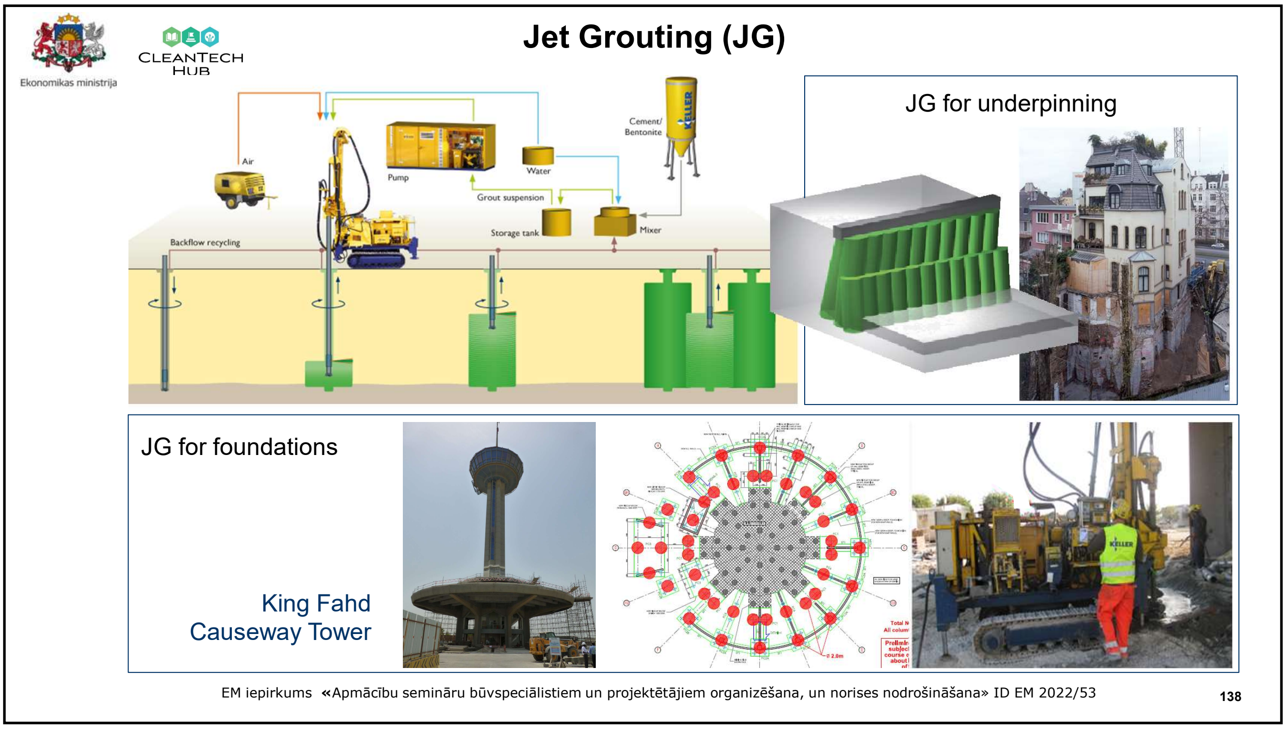
Ekonomikas ministrija
CLEANTECH HUB
Jet Grouting (JG)
Air
Pump
Water
Cement/ Bentonite
Grout suspension
Storage tank
Mixer
Backflow recycling
JG for underpinning
JG for foundations
King Fahd
Causeway Tower
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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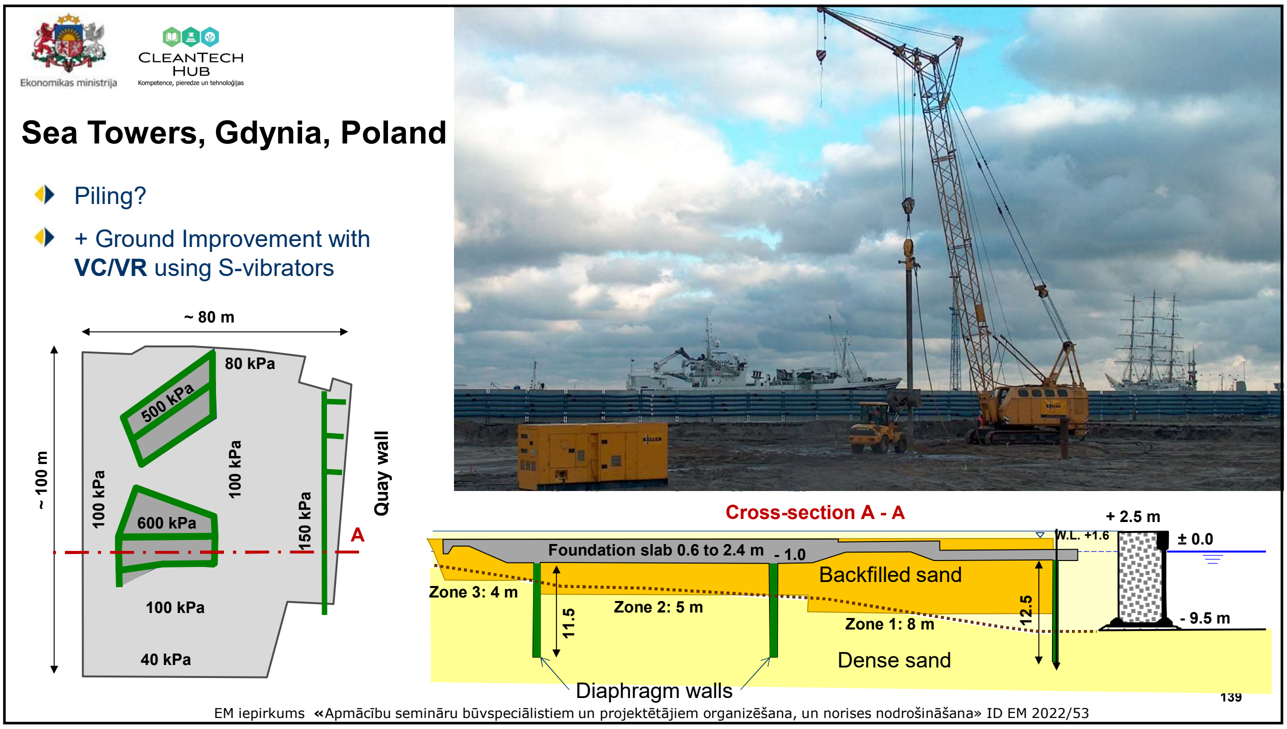
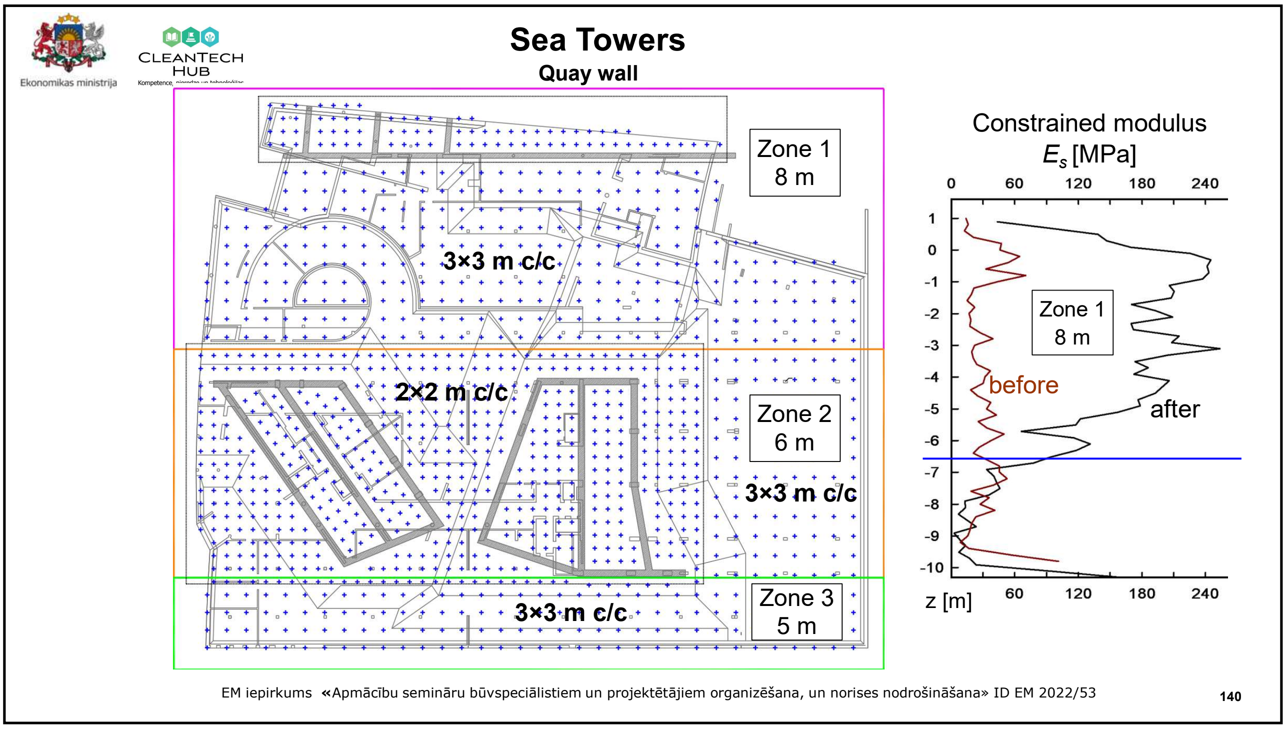

Ekonomikas ministrija
CLEANTECH HUB
Sea Towers, Gdynia, Poland
Piling?
+ Ground Improvement with VC/VR using S-vibrators
~ 80 m
~ 100 m
80 kPa
500 kPa
100 kPa
100 kPa
150 kPa
600 kPa
100 kPa
40 kPa
Quay wall
A
Cross-section A - A
+ 2.5 m
± 0.0
W.L. +1.6
Foundation slab 0.6 to 2.4 m
- 1.0
Backfilled sand
Zone 3: 4 m
Zone 2: 5 m
Zone 1: 8 m
11.5
12.5
- 9.5 m
Dense sand
Diaphragm walls
139
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53


Ekonomikas ministrija
CLEANTECH HUB
Sea Towers
Quay wall
Zone 1
8 m
3×3 m c/c
2×2 m c/c
Zone 2
6 m
3×3 m c/c
Zone 3
5 m
3×3 m c/c
Constrained modulus
E_s [MPa]
0
60
120
180
240
Zone 1
8 m
before
after
z [m]
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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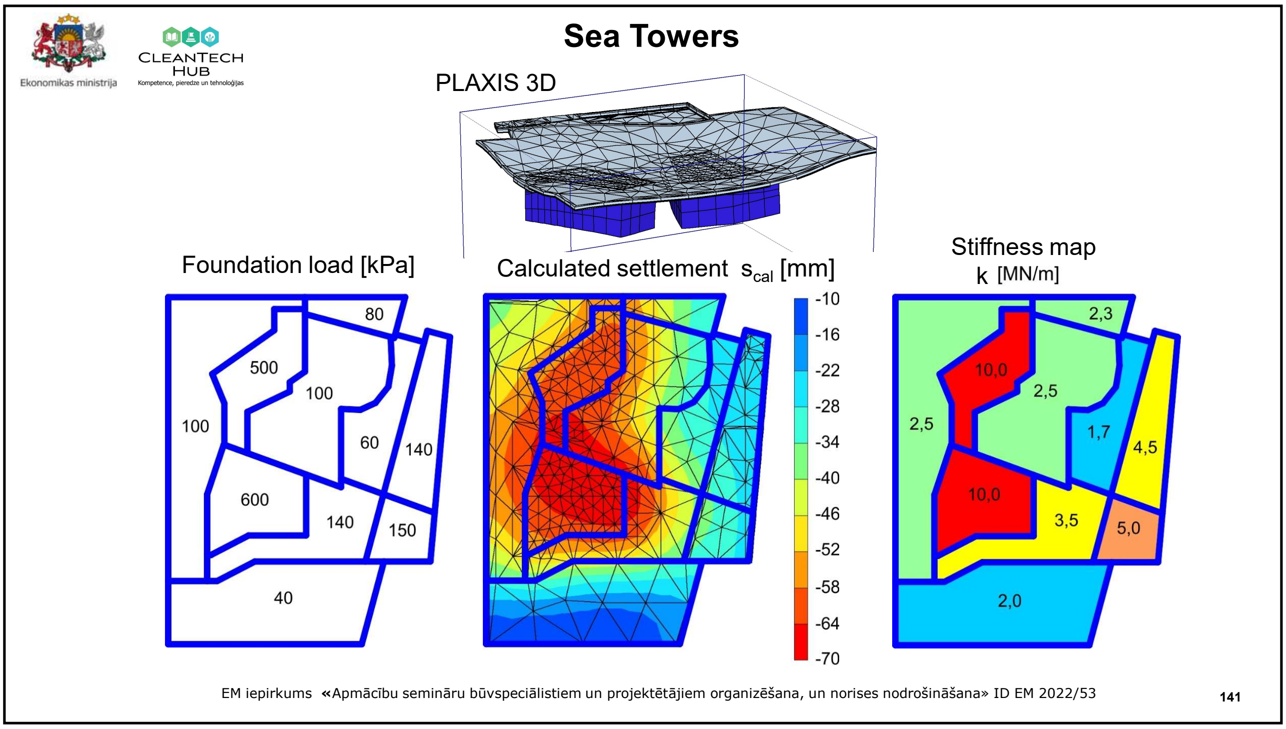
Ekonomikas ministrija
CLEANTECH HUB
Sea Towers
PLAXIS 3D
Foundation load [kPa]
80
500
100
100
60
140
600
140
150
40
Calculated settlement s_{cal} [mm]
-10
-16
-22
-28
-34
-40
-46
-52
-58
-64
-70
Stiffness map
k [MN/m]
2,3
10,0
2,5
2,5
1,7
4,5
10,0
3,5
5,0
2,0
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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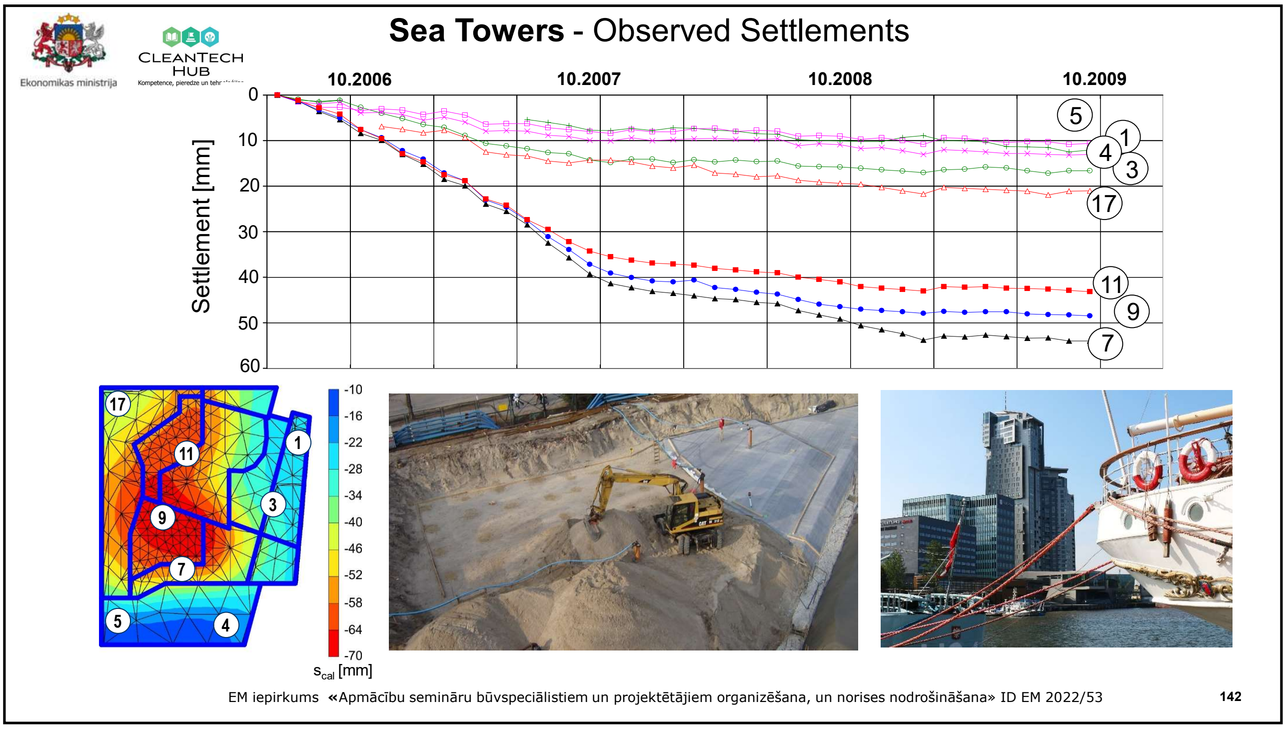
Ekonomikas ministrija
CLEANTECH HUB
Sea Towers - Observed Settlements
10.2006
10.2007
10.2008
10.2009
Settlement [mm]
0
10
20
30
40
50
60
5
1
4
3
17
11
9
7
-10
-16
-22
-28
-34
-40
-46
-52
-58
-64
-70
s_{cal} [mm]
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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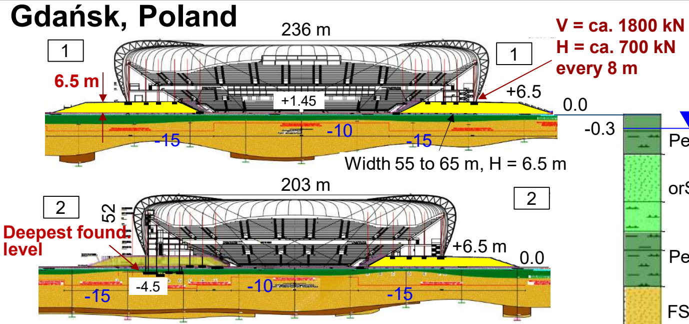
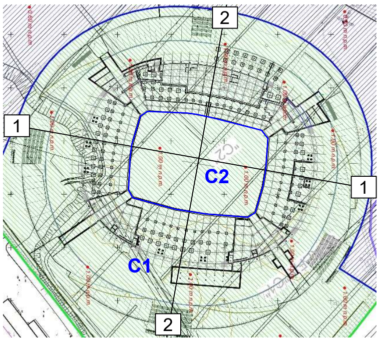
Ekonomikas ministrija | CLEANTECH HUB Kompetence, pieredze un tehnoloģijas

Stadium in Gdańsk, Poland (VC + DC)

Total area 27.6 ha





Two independent tenders/contracts:

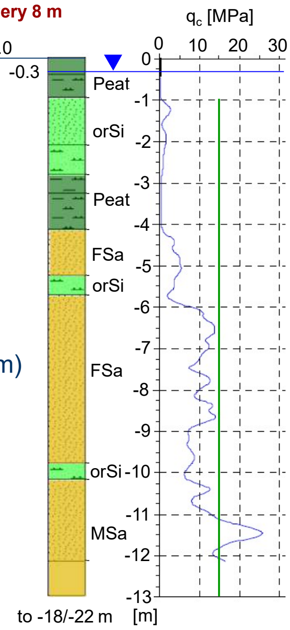
Requirements for C1 + C2 (8.75 ha):

1: Soil exchange (324,000 m^3, av. 3.7 m, max 5.5 m)

2: Deep compaction
- C1 (foundations): $q_c \geq 15$ MPa to 15 m depth,
- C2 (playing field): $q_c \geq 15$ MPa to 10 m depth

3: Superficial compaction: final W.L. at +0.7 m
- C1: E_{v2} = 100 MPa, C2: E_{v2} = 80 MPa, Io ≤ 2.5

"Anticipated":
300 kPa bearing cap.; s=30 mm; Δs=10 mm



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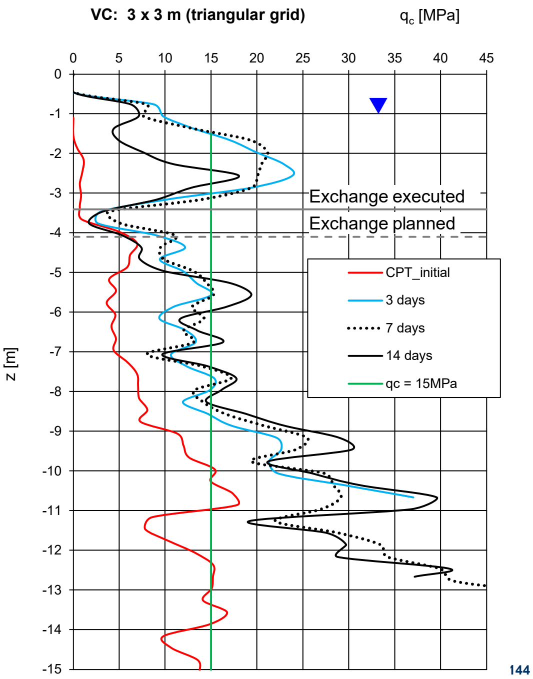
Ekonomikas ministrija | CLEANTECH HUB Kompetence, pieredze un tehnoloģijas

Stadium in Gdańsk

VC, from W.L. at +0.7 m, **1.27 mil. m^3**
C1 - to 15 m,
C2 – to 10 m



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājie organizēšana, un norises nodrošināšana» ID EM 2022/53

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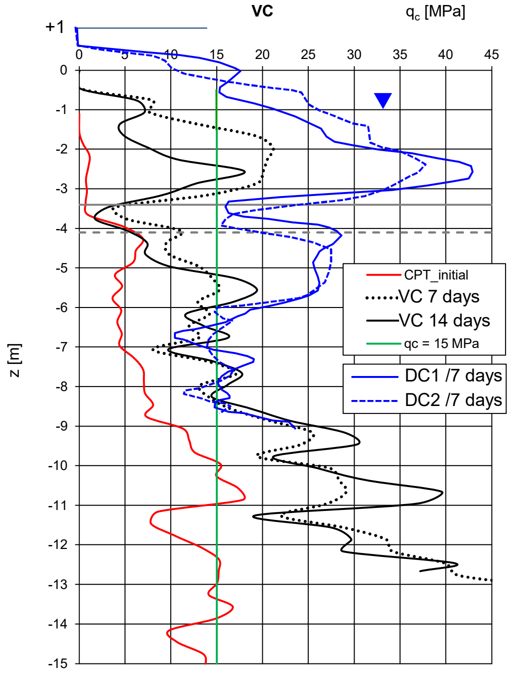
Stadium in Gdańsk



DC, from W.L. at +1.7 m
16 ton, H = 10 to 19 m
550 kJ/m^3

Area C1+C2
8.75 ha

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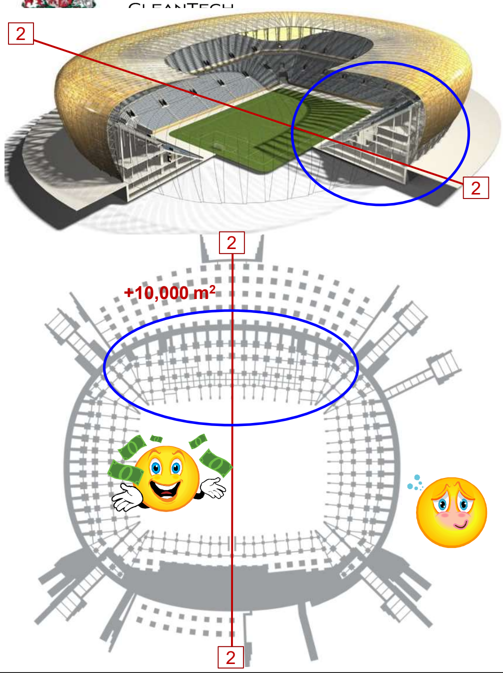
Stadium in Gdańsk



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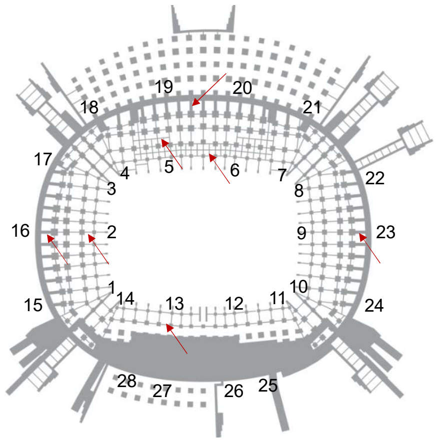
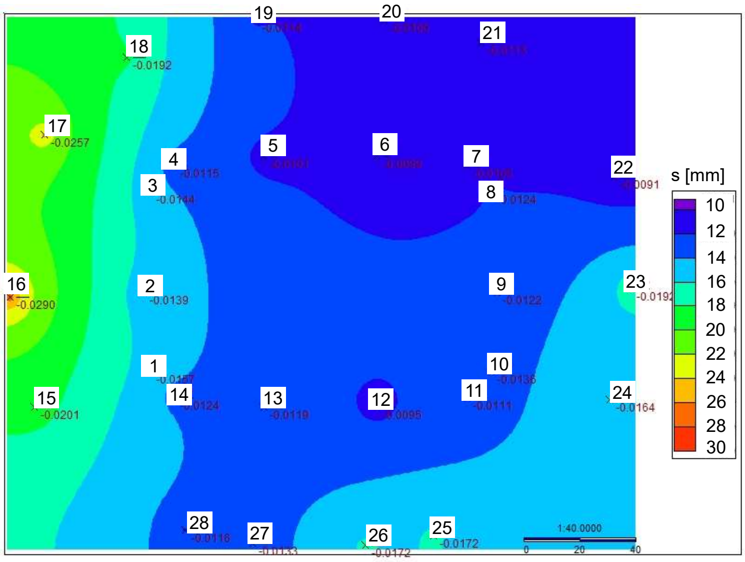
Stadium in Gdańsk

Observed settlement (1 year after completion)





EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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Polish Airlines LOT HQ, Warsaw, Poland (SC)

- 8-storey building, with glass façade sensitive to subsidence
- Foundation slab 100×65×1.2 m
- Aver. characteristic foundation pressure **125 kPa**
- Max. allowable diff. settlement 1:500
- Max. allowable total settlement **25 mm**

EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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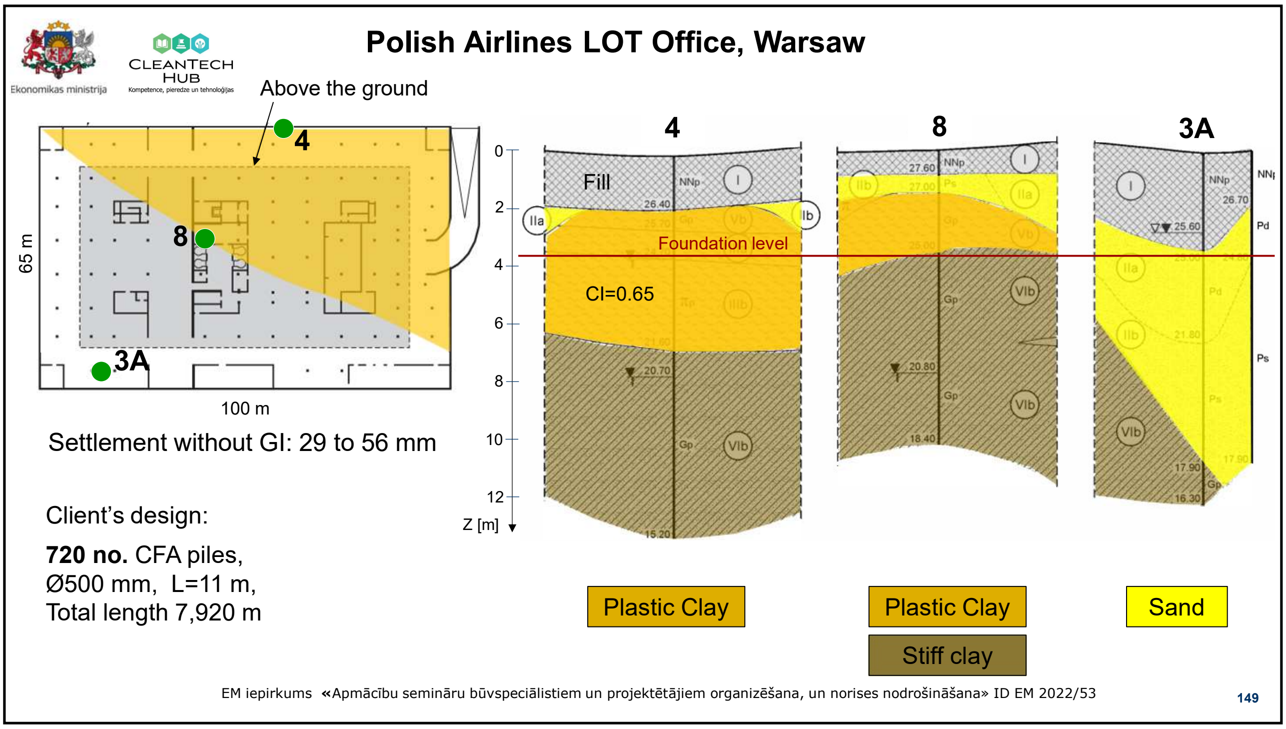
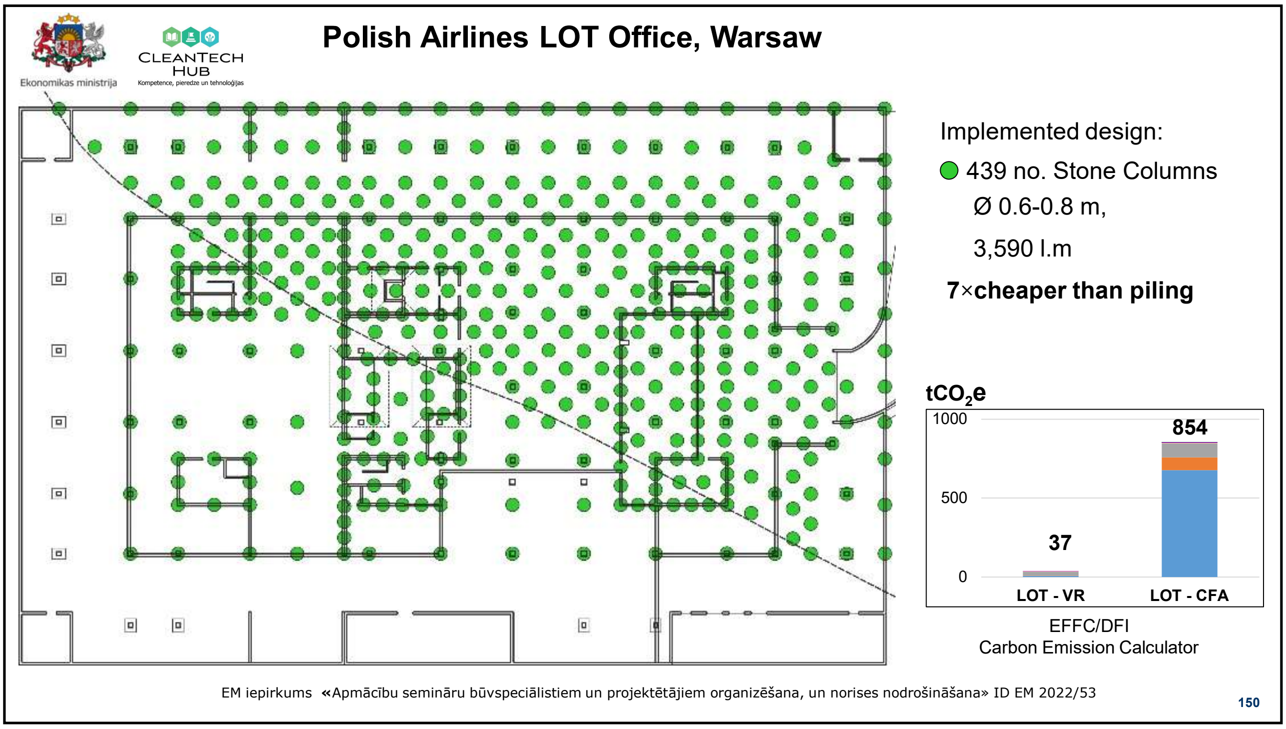
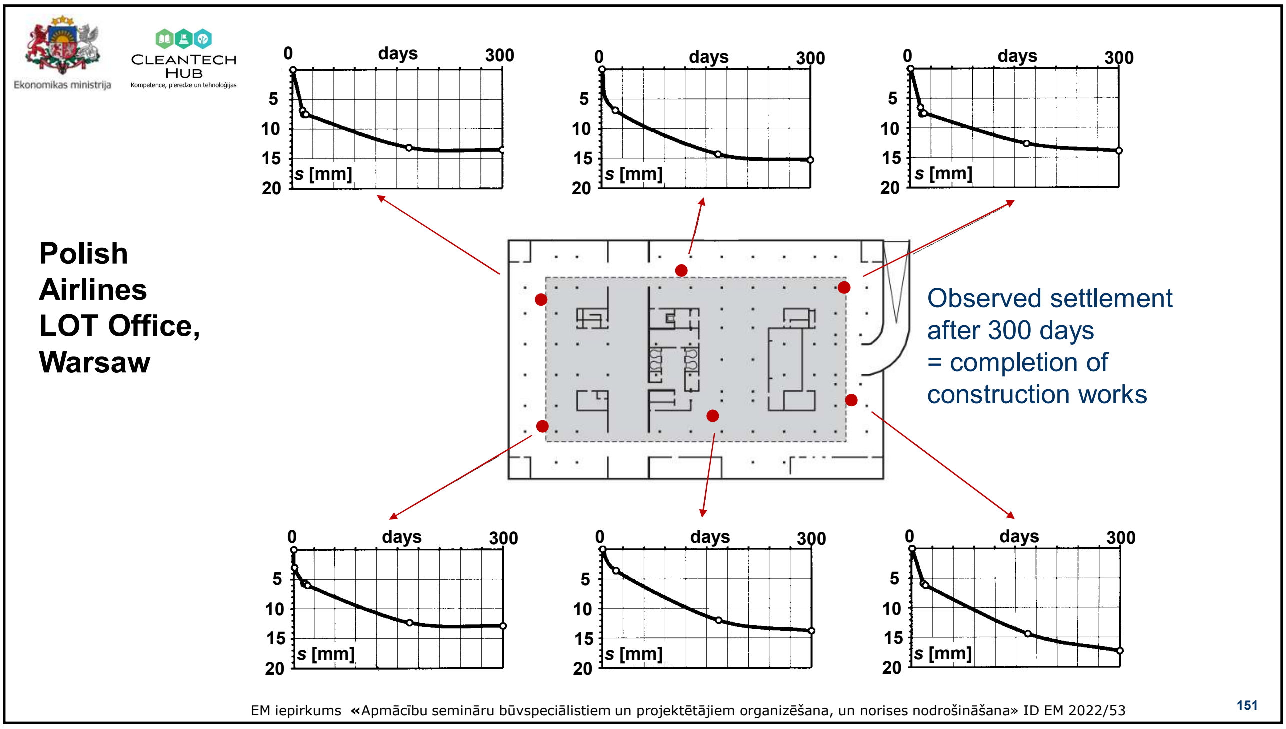

Polish Airlines LOT Office, Warsaw
Ekonomikas ministrija
CLEANTECH HUB
Above the ground
4
8
3A
65 m
100 m
Settlement without GI: 29 to 56 mm
Client's design:
720 no. CFA piles,
Ø500 mm, L=11 m,
Total length 7,920 m
Z [m]
Fill
Foundation level
CI=0.65
Plastic Clay
Plastic Clay
Stiff clay
Sand
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
149


Polish Airlines LOT Office, Warsaw
Ekonomikas ministrija
CLEANTECH HUB
Implemented design:
439 no. Stone Columns
Ø 0.6-0.8 m,
3,590 l.m
7×cheaper than piling
tCO2e
1000
500
0
37
854
LOT - VR
LOT - CFA
EFFC/DFI
Carbon Emission Calculator
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
150



Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Polish Airlines LOT Office, Warsaw
0
days
300
5
10
15
20
s [mm]
Observed settlement after 300 days = completion of construction works
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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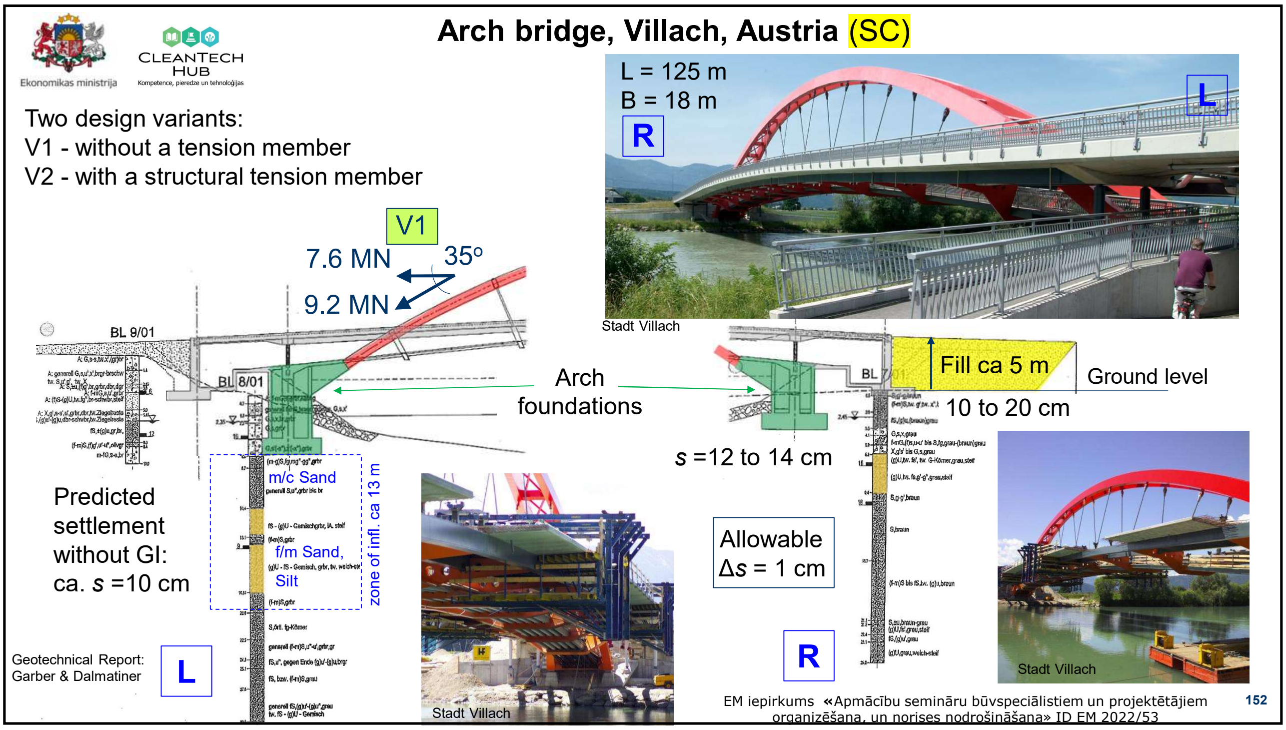

Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Arch bridge, Villach, Austria (SC)
Two design variants:
V1 - without a tension member
V2 - with a structural tension member
L = 125 m
B = 18 m
R
L
Stadt Villach
V1
7.6 MN
35°
9.2 MN
BL 9/01
BL 8/01
Arch
foundations
Fill ca 5 m
Ground level
10 to 20 cm
s =12 to 14 cm
m/c Sand
f/m Sand, Silt
zone of infl. ca 13 m
Predicted settlement without GI: ca. s =10 cm
Allowable Δs = 1 cm
Geotechnical Report: Garber & Dalmatiner
L
R
Stadt Villach
Stadt Villach
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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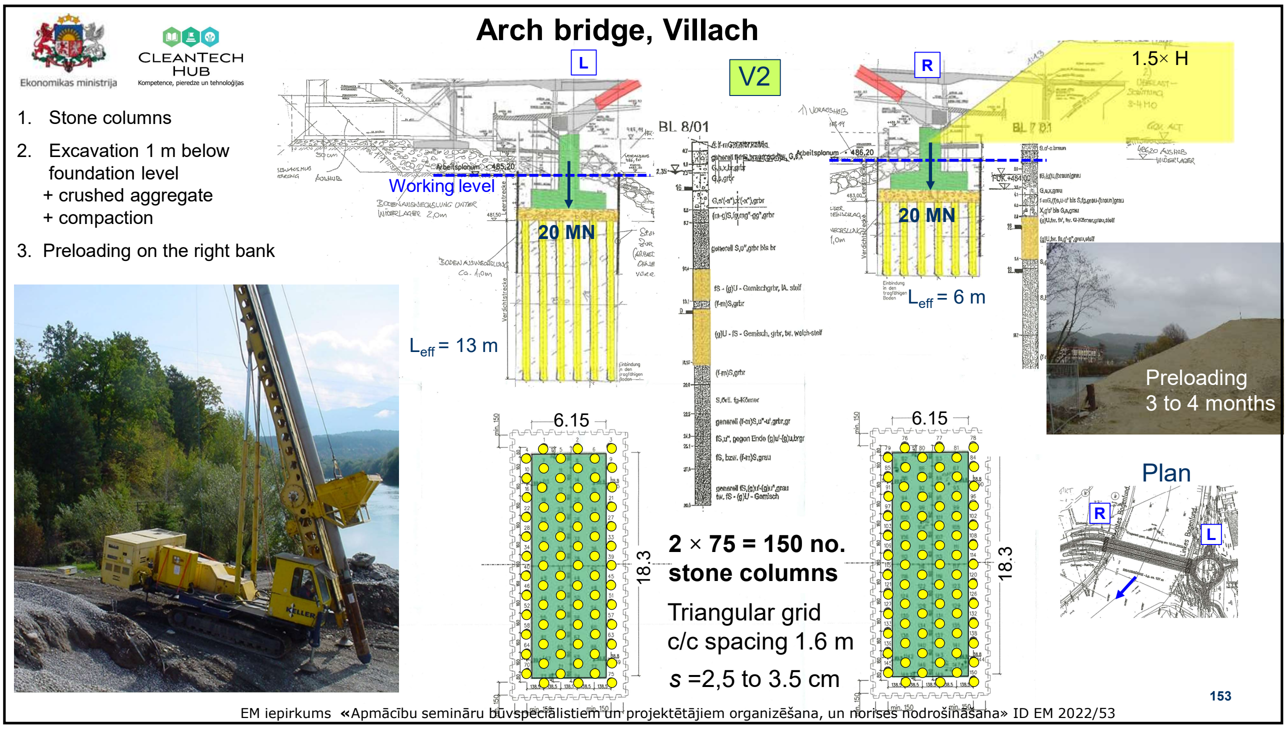
Arch bridge, Villach
Ekonomikas ministrija
CLEANTECH HUB
1. Stone columns
2. Excavation 1 m below foundation level
+ crushed aggregate
+ compaction
3. Preloading on the right bank
L
V2
R
1.5× H
Working level
20 MN
20 MN
Leff = 13 m
Leff = 6 m
Preloading
3 to 4 months
Plan
6.15
6.15
18.3
18.3
2 × 75 = 150 no. stone columns
Triangular grid
c/c spacing 1.6 m
s =2,5 to 3.5 cm
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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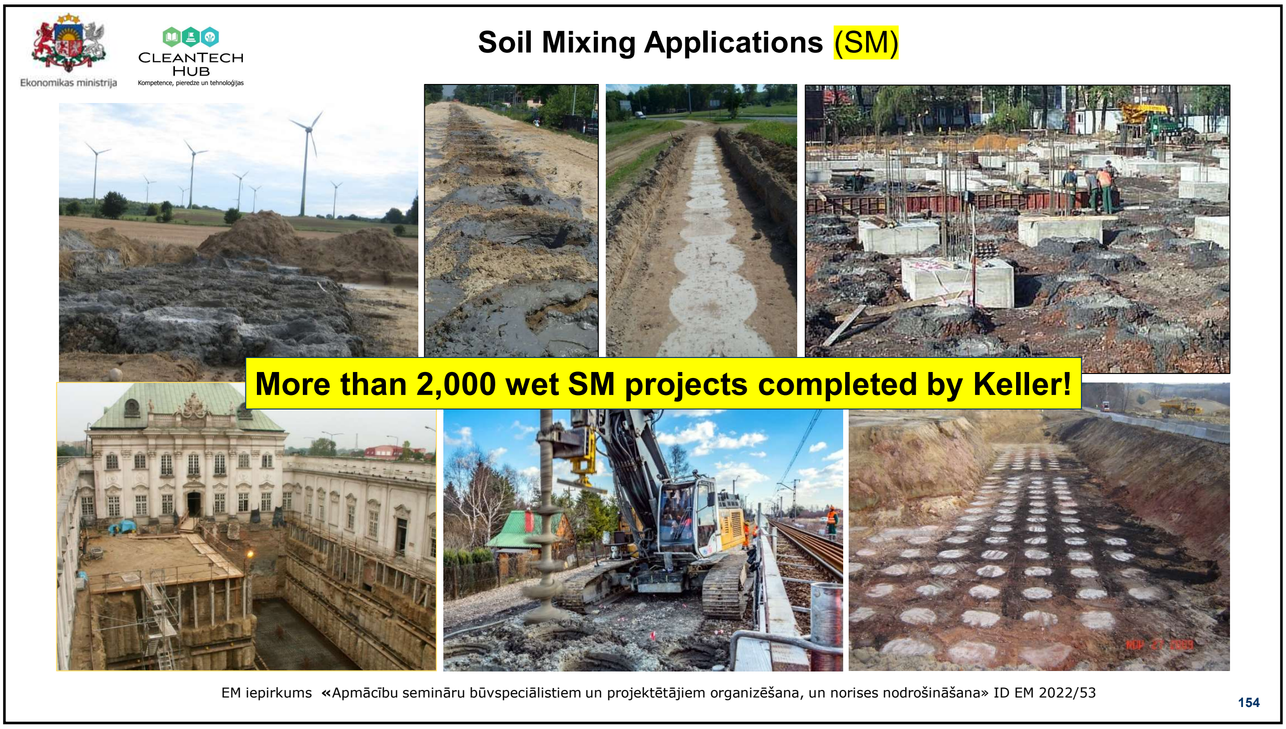
Soil Mixing Applications (SM)
Ekonomikas ministrija
CLEANTECH HUB
More than 2,000 wet SM projects completed by Keller!
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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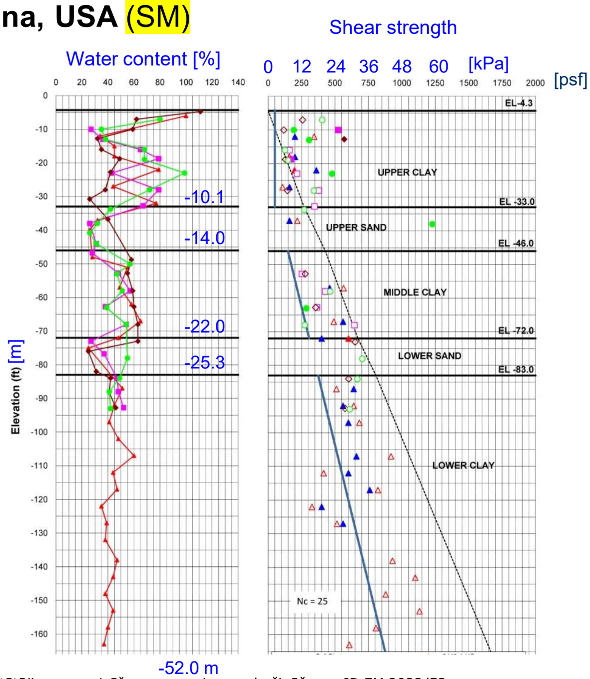
Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

Large Tanks, Louisiana, USA (SM)

22 oil tanks (LOOP LLC)
D = **90 m**
H = **15 m**
V = **95,000 m³**



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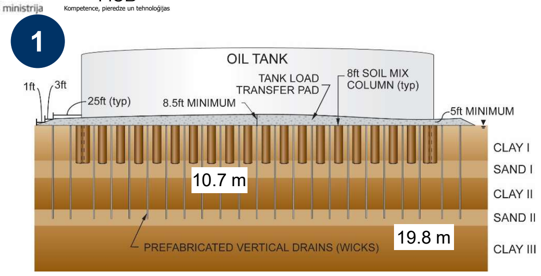
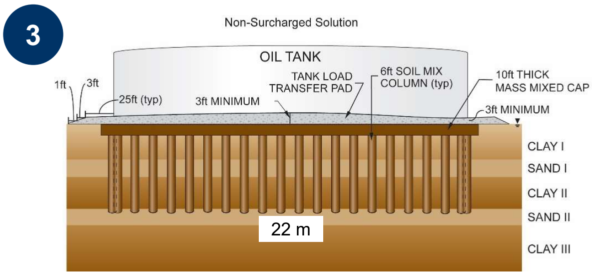
Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

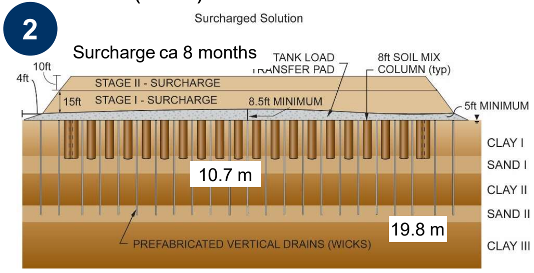
Large Tanks, Louisiana



2 Tanks (2001)



10 Tanks (2010, 2015)



10 Tanks (2002, 2003, 2007)

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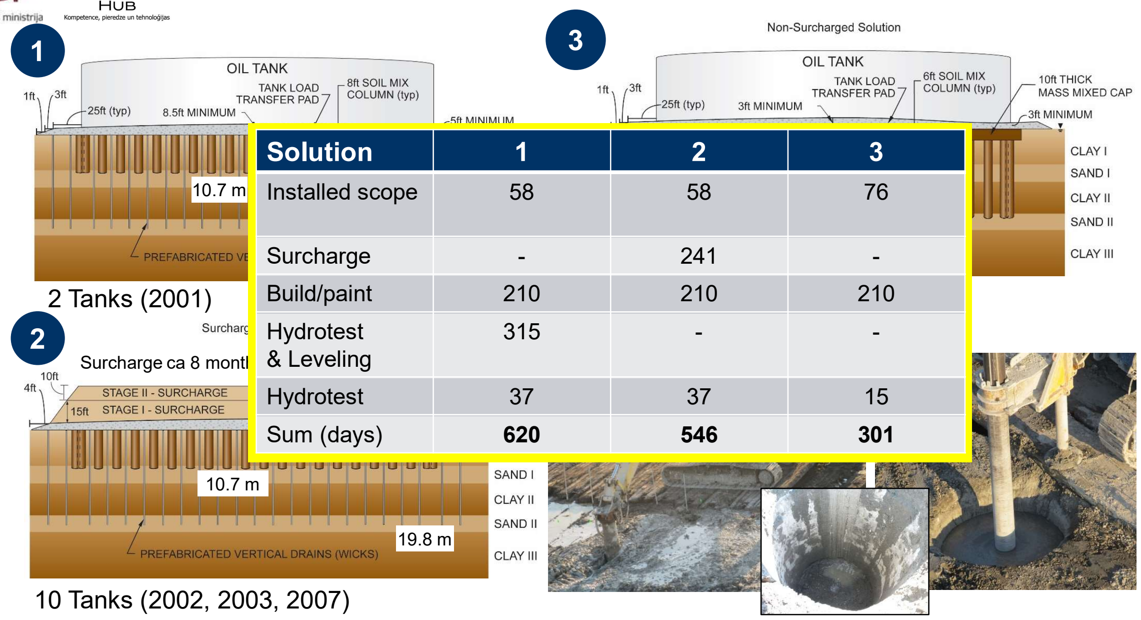
Large Tanks, Louisiana



Solution	1	2	3
Installed scope	58	58	76
Surcharge	-	241	-
Build/paint	210	210	210
Hydrotest & Leveling	315	-	-
Hydrotest	37	37	15
Sum (days)	**620**	**546**	**301**

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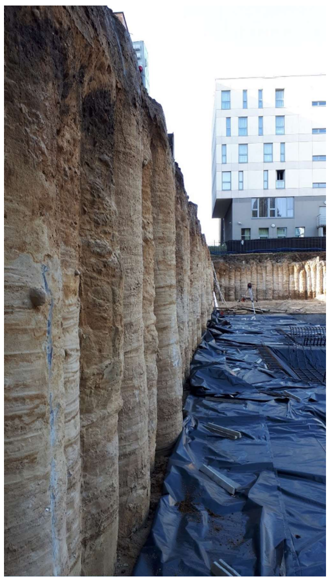
Excavation control (DSM)



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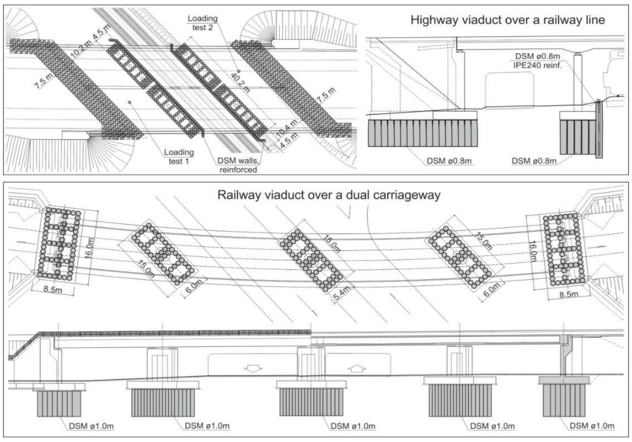
Bridges on DSM columns

Typical design criteria:
s_{max} = 20-30 mm and Δs = 10 mm

Since 2002 more than **400** road and railway bridges founded on DSM columns in Poland



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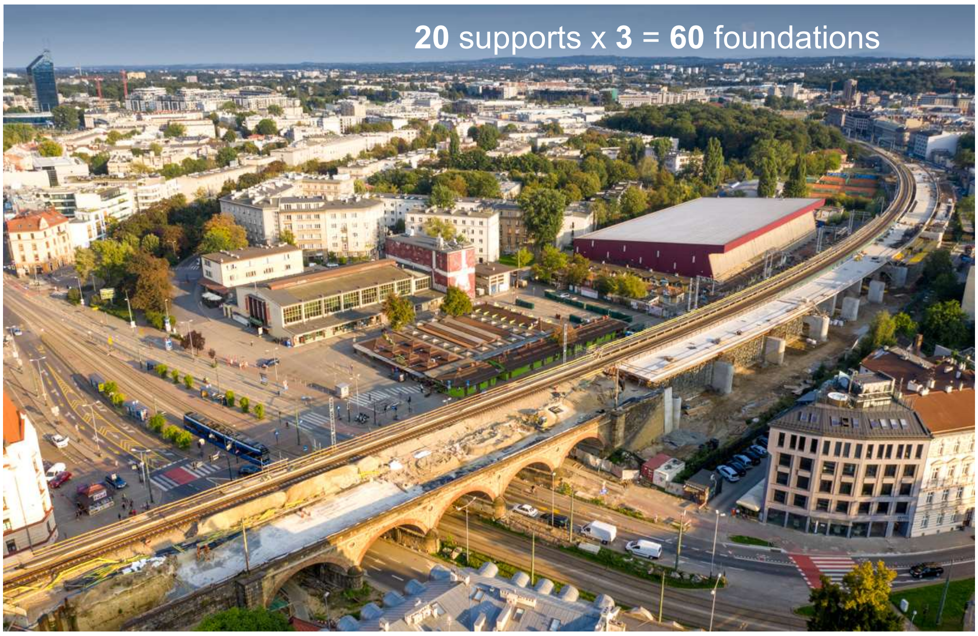
Railway Flyover, Cracow, Poland (DSM)



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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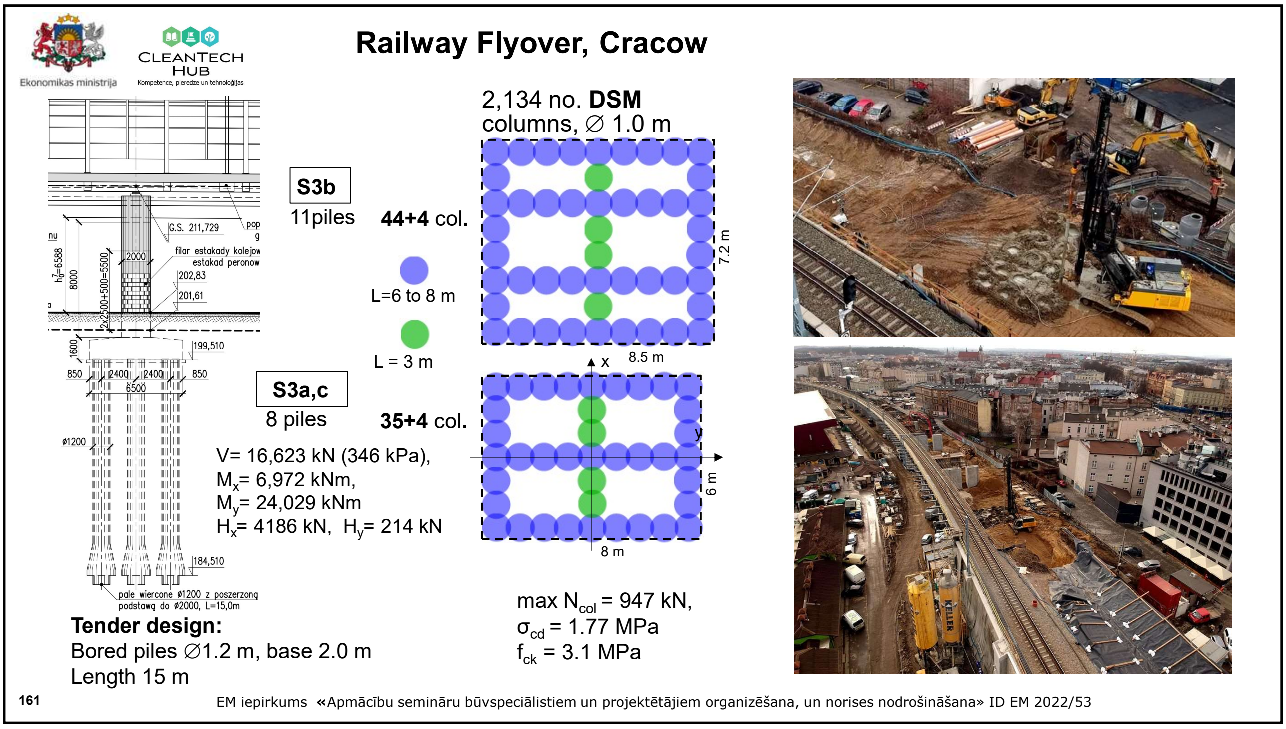
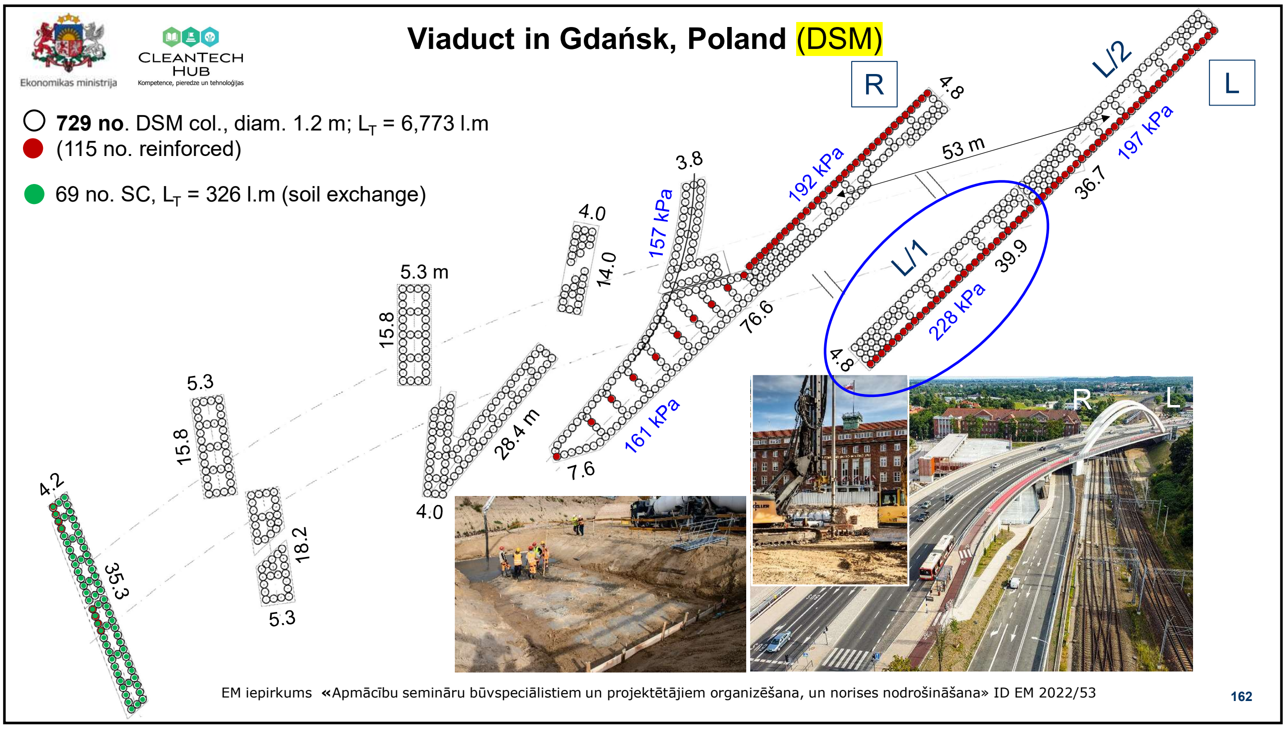

Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Railway Flyover, Cracow
2,134 no. DSM columns, ∅ 1.0 m
S3b
11piles
44+4 col.
L=6 to 8 m
L = 3 m
7.2 m
8.5 m
S3a,c
8 piles
35+4 col.
6 m
8 m
V= 16,623 kN (346 kPa),
Mx= 6,972 kNm,
My= 24,029 kNm
Hx= 4186 kN, Hy= 214 kN
max Ncol = 947 kN,
σcd = 1.77 MPa
fck = 3.1 MPa
Tender design:
Bored piles ∅1.2 m, base 2.0 m
Length 15 m
161
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53


Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Viaduct in Gdańsk, Poland (DSM)
729 no. DSM col., diam. 1.2 m; LT = 6,773 l.m
(115 no. reinforced)
69 no. SC, LT = 326 l.m (soil exchange)
R
L
L/2
L/1
4.8
53 m
192 kPa
197 kPa
36.7
39.9
228 kPa
3.8
4.0
157 kPa
14.0
76.6
5.3 m
15.8
161 kPa
28.4 m
7.6
4.0
5.3
15.8
18.2
4.2
35.3
5.3
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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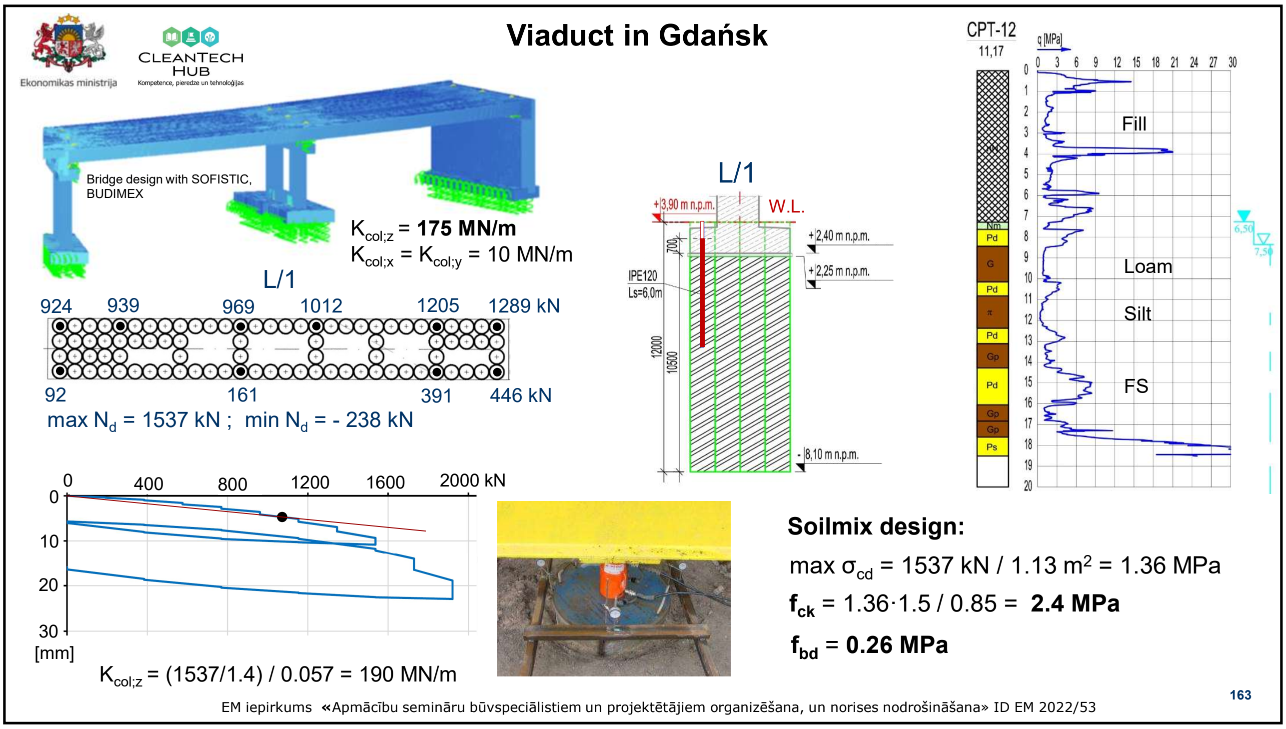
Viaduct in Gdańsk
Ekonomikas ministrija
CLEANTECH HUB
Bridge design with SOFISTIC, BUDIMEX
Kcol;z = 175 MN/m
Kcol;x = Kcol;y = 10 MN/m
L/1
924 939 969 1012 1205 1289 kN
92 161 391 446 kN
max Nd = 1537 kN ; min Nd = - 238 kN
0 400 800 1200 1600 2000 kN
0 10 20 30 [mm]
Kcol;z = (1537/1.4) / 0.057 = 190 MN/m
L/1
W.L.
IPE120
Ls=6,0m
CPT-12
Fill
Loam
Silt
FS
Soilmix design:
max σcd = 1537 kN / 1.13 m² = 1.36 MPa
fck = 1.36·1.5 / 0.85 = 2.4 MPa
fbd = 0.26 MPa
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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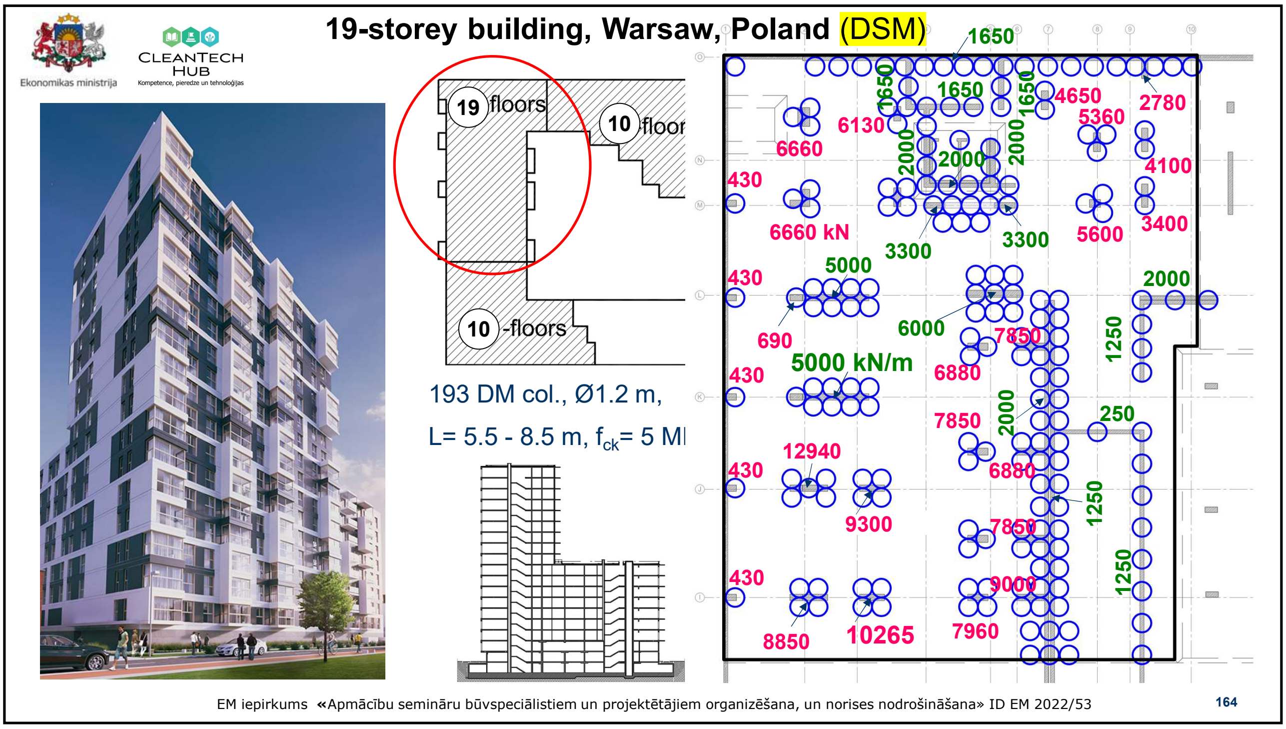
19-storey building, Warsaw, Poland (DSM)
Ekonomikas ministrija
CLEANTECH HUB
19 floors
10 floors
10 -floors
193 DM col., Ø1.2 m,
L= 5.5 - 8.5 m, fck= 5 MI
6660 kN
5000 kN/m
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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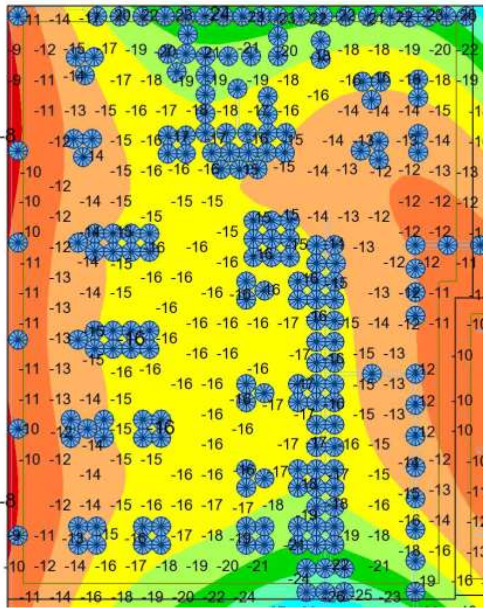
Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

19-storey building, Warsaw

k_{column} = 75 MN/m,
k_{ground} = 8.5 MPa/m

Predicted settlement [mm]



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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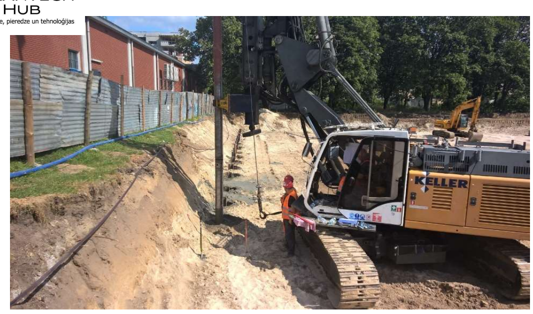
Ekonomikas ministrija

CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas

19-storey building, Warsaw



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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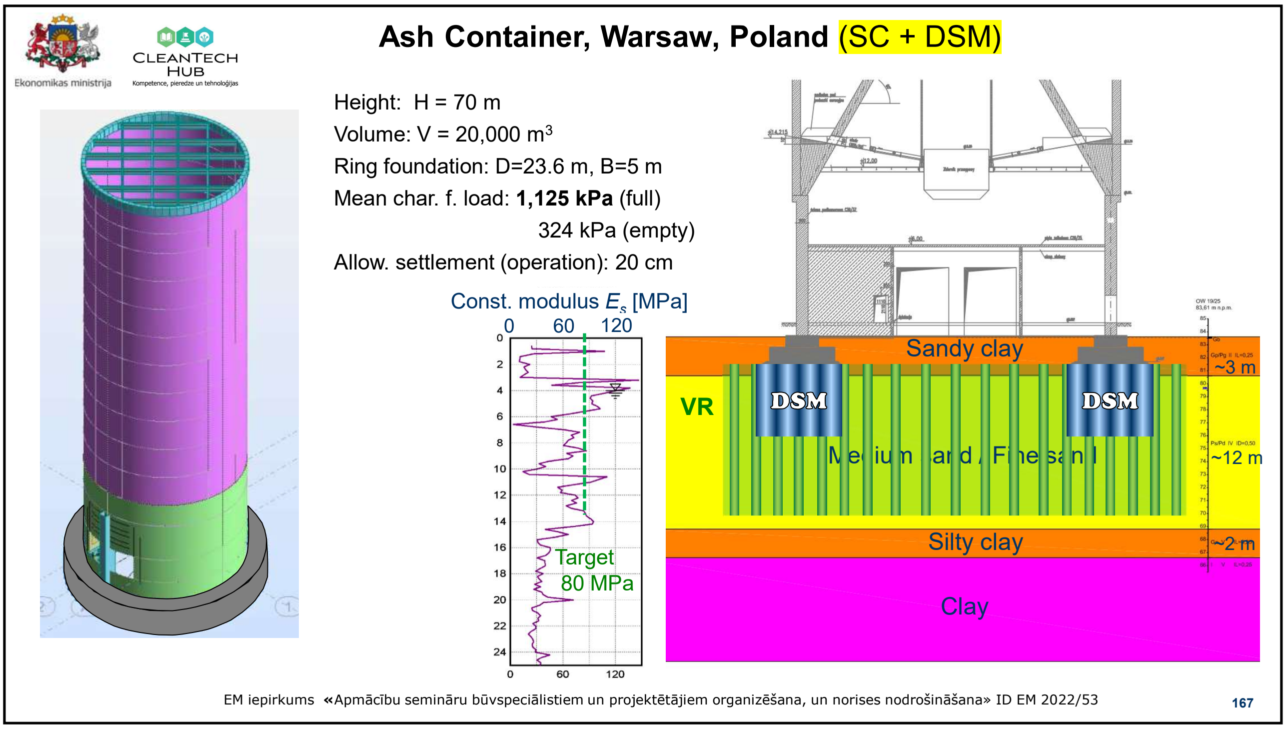
Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Ash Container, Warsaw, Poland (SC + DSM)
Height: H = 70 m
Volume: V = 20,000 m3
Ring foundation: D=23.6 m, B=5 m
Mean char. f. load: 1,125 kPa (full)
324 kPa (empty)
Allow. settlement (operation): 20 cm
Const. modulus Es [MPa]
0 60 120
Target
80 MPa
Sandy clay
~3 m
VR
DSM
DSM
Medium and Fine sand
~12 m
Silty clay
~2 m
Clay
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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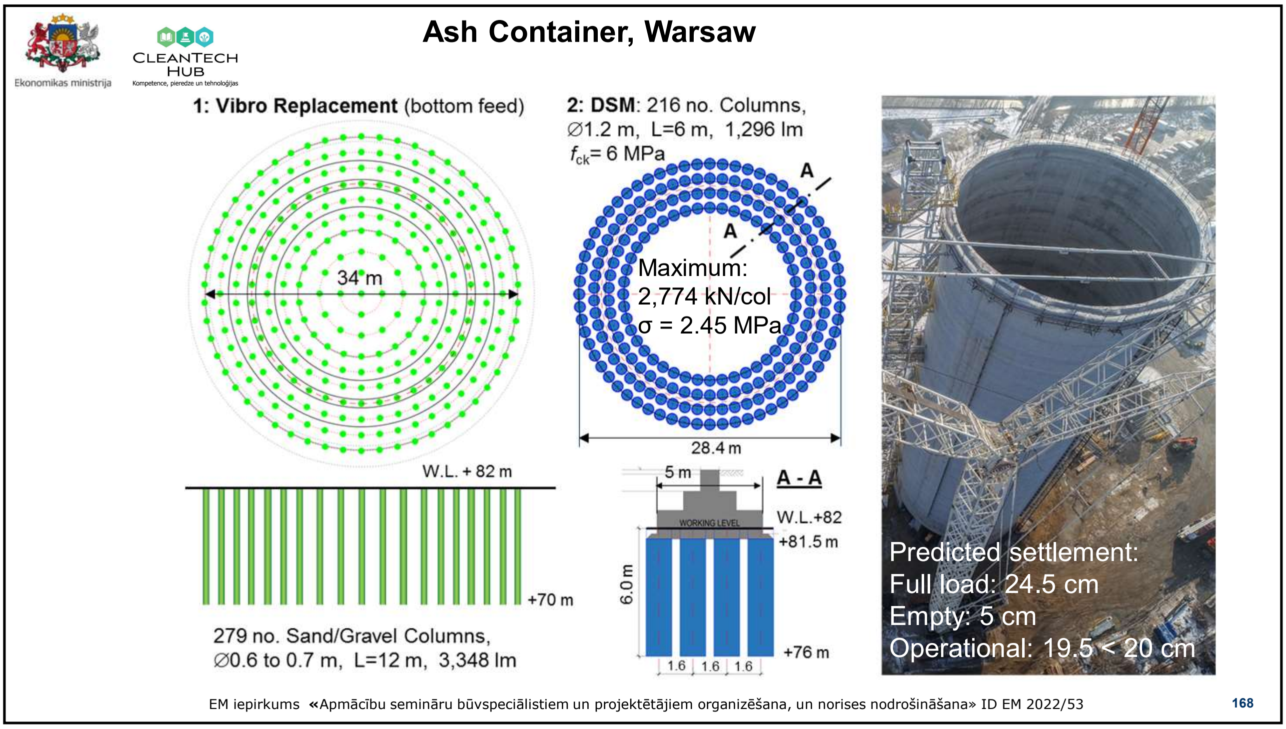
Ekonomikas ministrija
CLEANTECH HUB
Kompetence, pieredze un tehnoloģijas
Ash Container, Warsaw
1: Vibro Replacement (bottom feed)
34 m
W.L. + 82 m
+70 m
279 no. Sand/Gravel Columns,
∅0.6 to 0.7 m, L=12 m, 3,348 lm
2: DSM: 216 no. Columns,
∅1.2 m, L=6 m, 1,296 lm
fck= 6 MPa
A
A
Maximum:
2,774 kN/col
σ = 2.45 MPa
28.4 m
5 m
A - A
WORKING LEVEL
W.L.+82
+81.5 m
6.0 m
+76 m
1.6 1.6 1.6
Predicted settlement:
Full load: 24.5 cm
Empty: 5 cm
Operational: 19.5 < 20 cm
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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PLAZA Centre, Rybnik, Poland (DSM)

Building founded on **187 no. footings**, each loaded up to 16,500 kN (des. load)

Char. pressure
330 to 550 kPa

Soil:
0 - 2 m loose Fill,
2 - 6.5 m silty Clay,
6.5 - 7.2 m coarse sand,
below stiff silty Clay

Original design:
1,010 no. CFA piles,
Ø 80 cm,
Length 12 m

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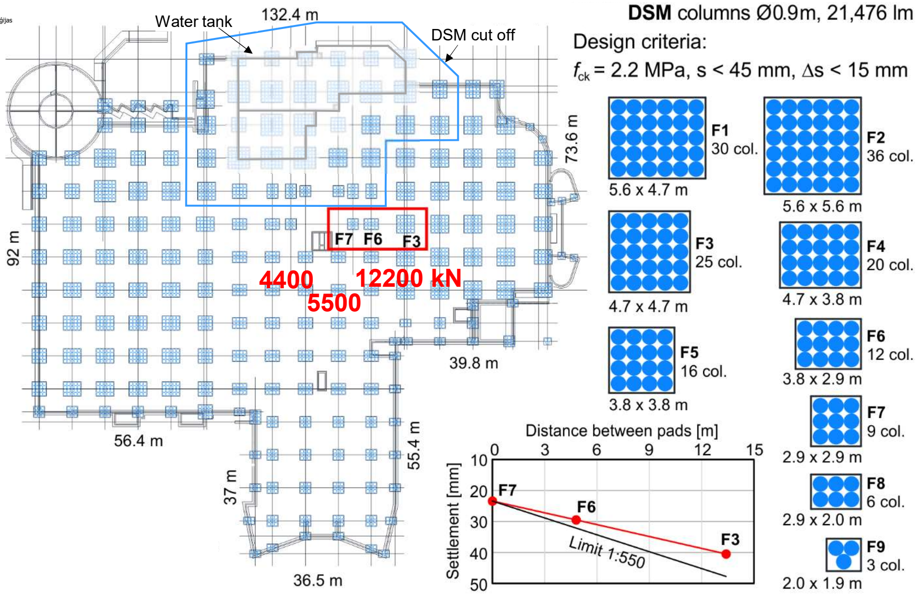
PLAZA Centre, Rybnik

DSM columns Ø0.9m, 21,476 lm
Design criteria:
f_{ck} = 2.2 MPa, s < 45 mm, Δs < 15 mm



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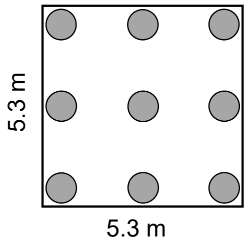
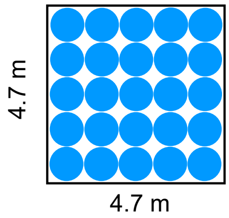
PLAZA Centre, Rybnik

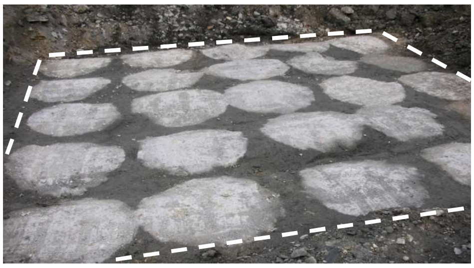
Footing F3: Characteristic load 12,200 kN (552 kPa)

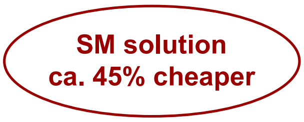


9 CFA piles



25 DSM Columns





Comparison:

Foundation system	Number	Mean length	Total length of piles / columns		Foundation volume [m³]		Reinforcement [kg]	
CFA piles, ∅ 0.8 m	1,154	12.0 m	13,848 m	+31%	4,535	-27%	227,000	-42%
DM col., ∅ 0.9 m	3,304	5.5 m	18,172 m		3,292		132,000	

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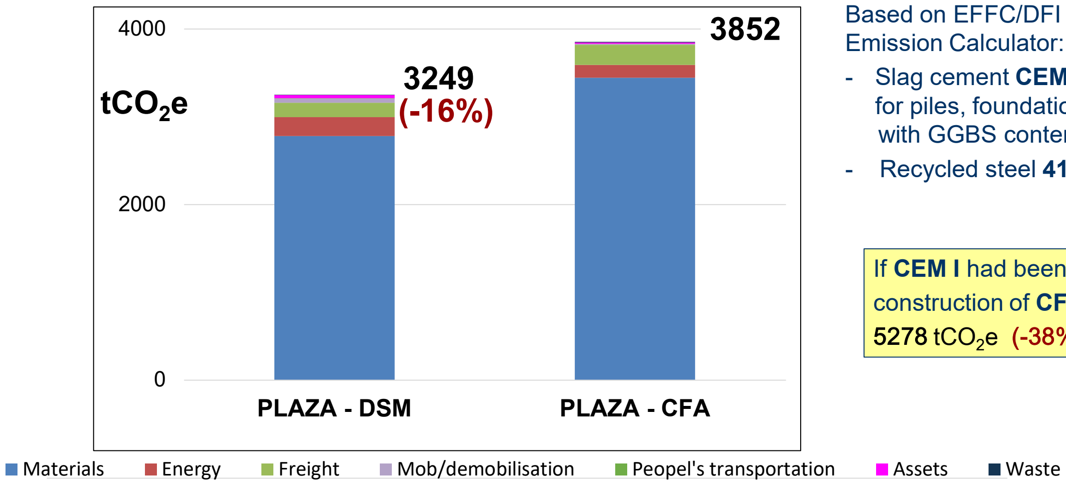
PLAZA Centre, Rybnik

Carbon footprint



Based on EFFC/DFI Carbon Emission Calculator:

- Slag cement **CEM IIIA** used for piles, foundations and DM, with GGBS content of **51%**
- Recycled steel **41%**

If **CEM I** had been used for construction of **CFA piles**: **5278** tCO_2e (-38%)

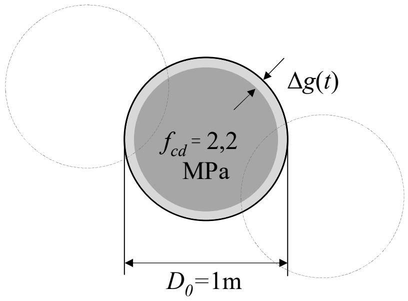
Solution	Volume, m³	Foundations, m³	Reinforcement, kg
CFA Piles	8,696	4,535	227,000
DM columns	11,554	3,292	132,000

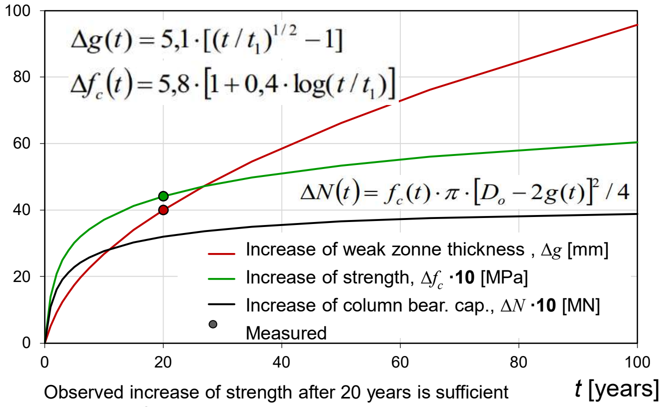
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53 172

Ekonomikas ministrija | CLEANTECH HUB Kompetence, pieredze un tehnoloģijas

Durability

- What about objects requiring design lifetime >100 years?
- Direct testing of SM columns?
- Experience with stabilization of soil by means of injection is >200 years old!
- EN 14679, EN 12716, FHWA 2013 do not limit long-term SM applications





Measured data:
Ikegami M., Ichiba T., Ohishi K., Terashi M. (2003):
f_c (93 days) = 5.8 MPa, soil: alluvial clay w_n= 80-100%
Δf_c (20 ys) = 4.4 MPa, increase proportional to log t
$\Delta g_{śr}$ (20 ys) = 40 mm (8%), increase proportional to $\sqrt{t}$
In weak zone: f_c = 0,3 to 1 MPa

Observed increase of strength after 20 years is sufficient to preserve full column bearing capacity in 165 years !

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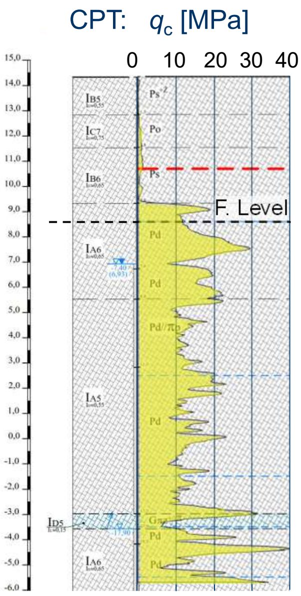
Ekonomikas ministrija | CLEANTECH HUB Kompetence, pieredze un tehnoloģijas

Olivia Star, Gdańsk, Poland (JG)



Loads:
Vertical (char.): 1,100 MN (**600 kPa**)
Moment (char.): 970 MNm
Vertical (des.): 1,650 MN (900 kPa)
Moment (des.): 1,600 MNm

EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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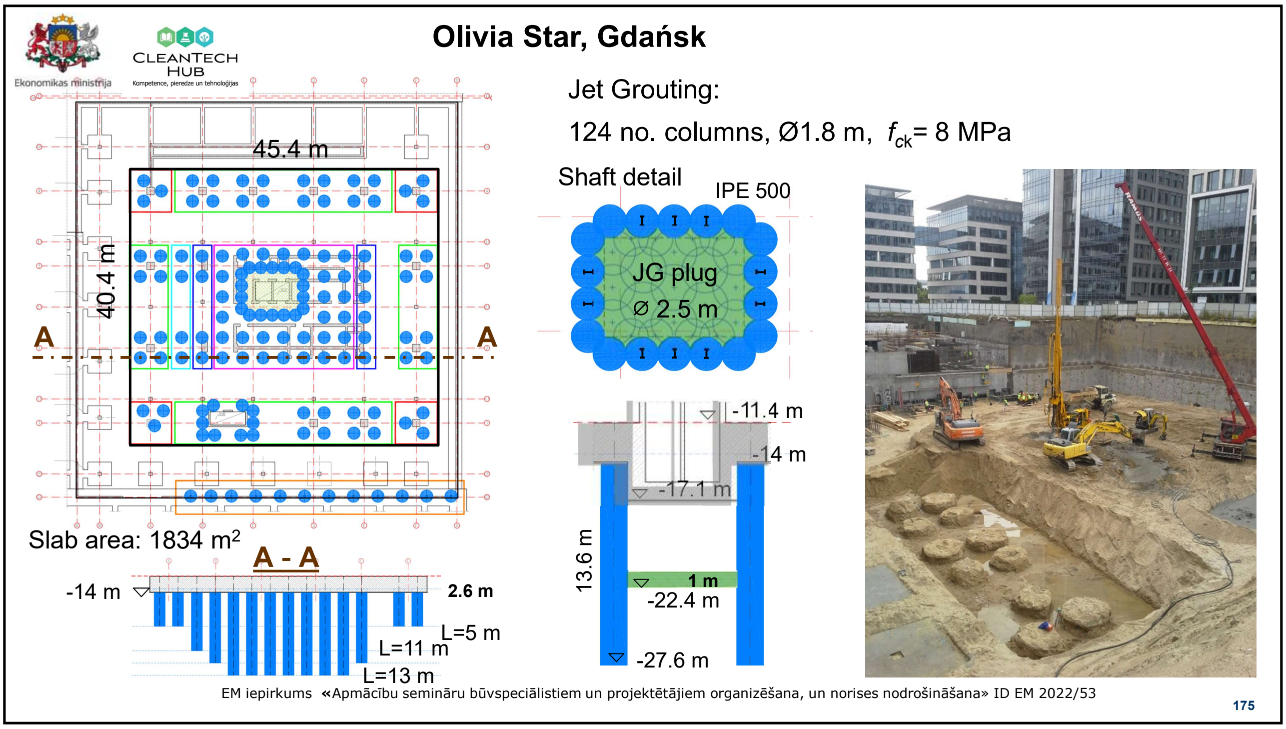
Ekonomikas ministrija
CLEANTECH HUB
Olivia Star, Gdańsk
Jet Grouting:
124 no. columns, Ø1.8 m, f_{ck}= 8 MPa
Shaft detail
IPE 500
JG plug
Ø 2.5 m
45.4 m
40.4 m
A
A
Slab area: 1834 m²
A - A
-14 m
2.6 m
L=5 m
L=11 m
L=13 m
-11.4 m
-14 m
-17.1 m
13.6 m
1 m
-22.4 m
-27.6 m
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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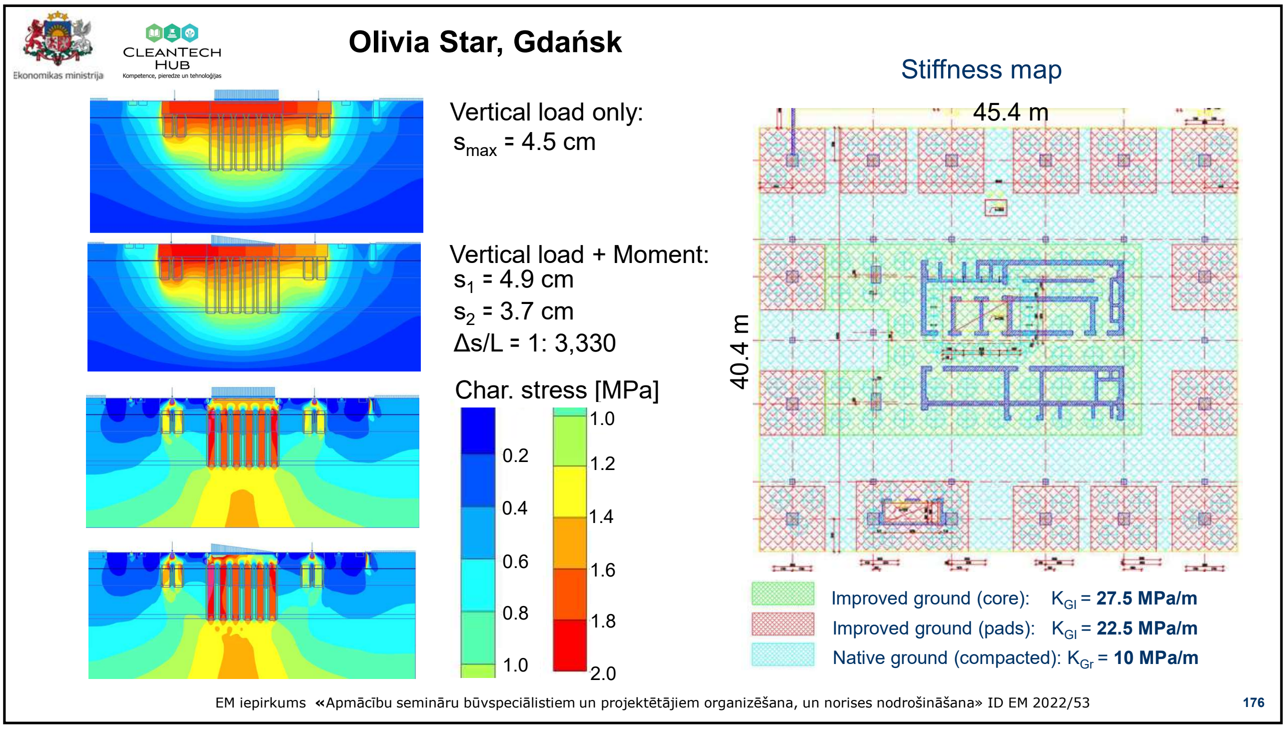
Ekonomikas ministrija
CLEANTECH HUB
Olivia Star, Gdańsk
Vertical load only:
s_{max} = 4.5 cm
Vertical load + Moment:
s_1 = 4.9 cm
s_2 = 3.7 cm
Δs/L = 1: 3,330
Char. stress [MPa]
0.2
0.4
0.6
0.8
1.0
1.0
1.2
1.4
1.6
1.8
2.0
Stiffness map
45.4 m
40.4 m
Improved ground (core): K_{Gl} = 27.5 MPa/m
Improved ground (pads): K_{Gl} = 22.5 MPa/m
Native ground (compacted): K_{Gr} = 10 MPa/m
EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53
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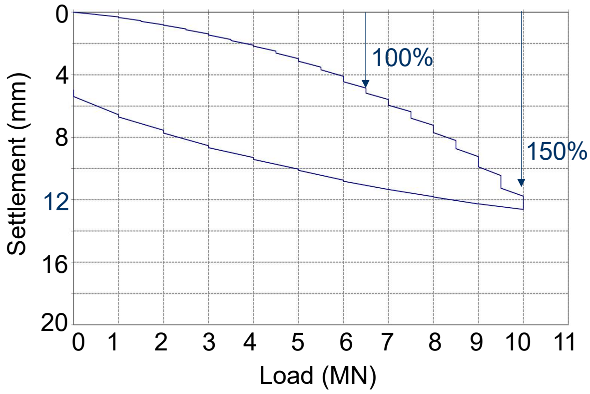
Olivia Star, Gdańsk

Loading test: JG column Ø1.8 m, L=11 m



EM iepirkums «Apmācību semināru būvspeciālistiem un projektētājiem organizēšana, un norises nodrošināšana» ID EM 2022/53

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Conclusions

- Tailored GI solutions allow fulfilment of tough design criteria also in case of heavily loaded and deformation sensitive structures. Close cooperation and good understanding between geotechnical and structural engineers is needed to achieve common goals
- Compared to traditional deep foundations systems, GI may offer (sometimes significant) savings in costs and time, can be more environmentally friendly and can reduce risks, and therefore is attractive for clients and contractors
- When designing bold GI solutions, we sometimes go beyond the comfort zone defined by standards and experience. Regulations shell not restrain development (prEC7 uses the wording 'comparable experience'), but one should always evaluate and manage associated risks. Extending GI to bold applications should be gradual, not abrupt.

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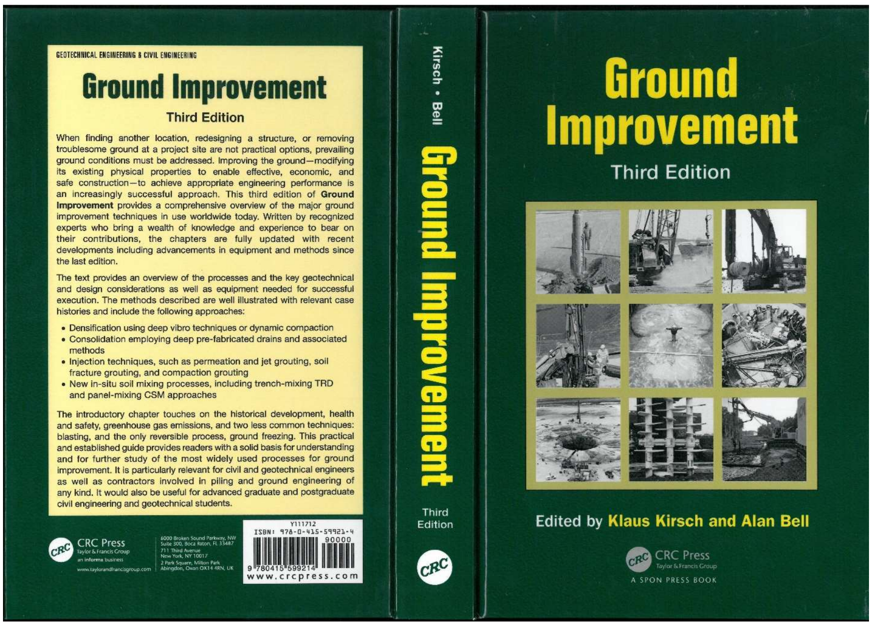

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Thank you for attention!

Questions & Answers

@EM_gov_lv,@siltinam /ekonomikasministrija www.em.gov.lv Brīvības iela 55, Rīga, LV-1519, Latvia +371 67013100 pasts@em.gov.lv