Ground improvement vs. pile foundations?

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ISSMGE TC211 contribution to the ETC-3 conference

Leuven, May 29, 2016

Topics

1. GI vs. PF - the wrong debate
2. Foundation concepts - back to the roots
3. Ground improvement by rigid inclusions
    - Failure mechanisms – ULS and stress domain
    - Load transfer platform (LTP) concept
    - GEO and STR design considerations
    - Execution methods & numerical modeling
4. Hybrid concept without load transfer platform
    - Soil mix as bearing elements - case history
5. Conclusions and perspectives

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1. GI vs PF – the wrong debate

Soil mix elements as bearing elements

= current trend on the foundation market

When we compare this solution with the classical piling one, it is generally the beginning of an irrelevant debate:

"How to conform the soil mix elements to the severe requirements imposed to concrete piles on the market?"

"Are the soil mix elements in agreement with the EC7-requirements for piles?" …

In this way of thinking, the soil mix element is at best

= a lower quality pile
= a cheaper pile
= a "second-hand" pile

1. GI vs PF – the wrong debate

Soil mix elements as bearing elements

How to compare soil mix elements with pile foundations?

Pile foundations	Soil mix elements
Well-established **design rules** (Eurocodes + National Annexes) with severe requirements	Lack of practical design guidelines – unclear situation
Well-known **material properties** (concrete, steel…)	Heterogeneous material with sometimes unmixed soft soil inclusions in the soil mix matrix
With European (CE) and local **markings** (e.g. Benor in Belgium) for the materials	Without marking or certification
With **QA/QC requirements** with regard to the material and concerning the execution	Lack of QA/QC requirements adapted to the functions of the soil mix elements

1. GI vs PF – the wrong debate

Soil mix elements as bearing elements

If the soil mix solution is selected…

the concrete industry highlights

- **the unbalanced requirements between both techniques**
- **the unfair competition between them**

"Why do we have to conform to severe and costly QA/QC rules for well-known and recognized technique and material while, when we work with an innovative technique such as the deep mixing, the requirements are more flexible or sometimes do not exist?"

There is thus a feeling of double standard politics on the market of foundation contractors…

1. GI vs PF – the wrong debate

Soil mix elements as bearing elements

But this is a wrong debate!

caused by the idea that a bearing soil mix element is a soil mix pile

→ Importance of the terminology

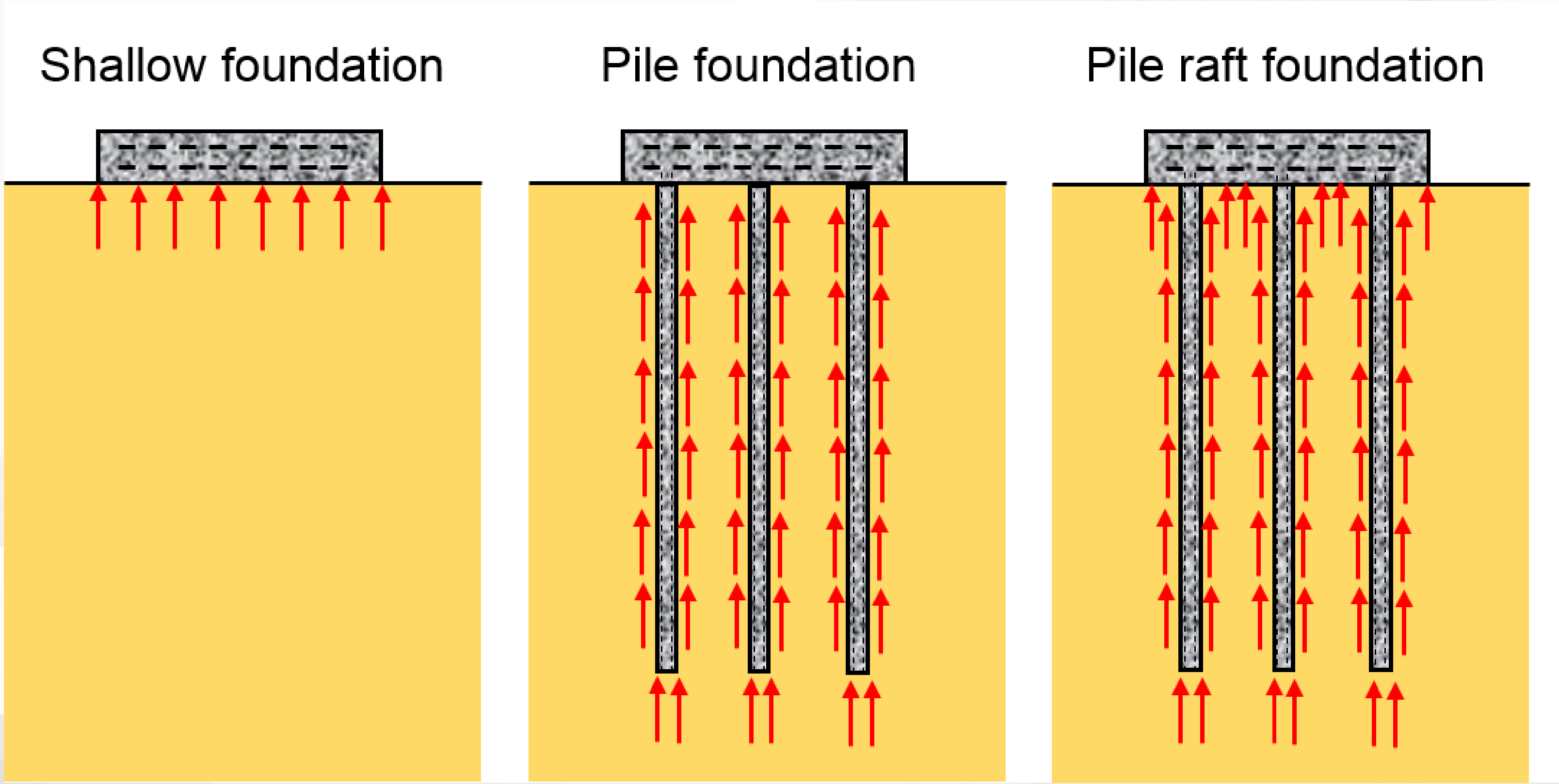
Please, use the terms soil-cement columns or soil mix panels

→ Importance of the definition of the foundation concept

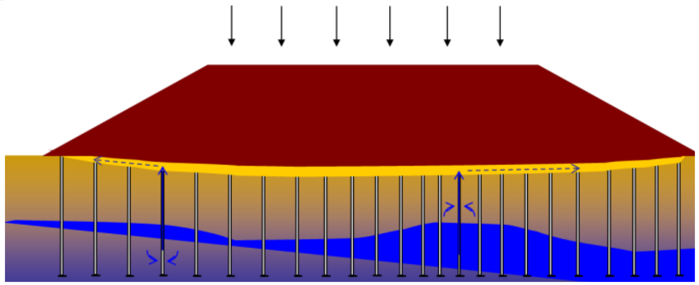
Back to the roots…

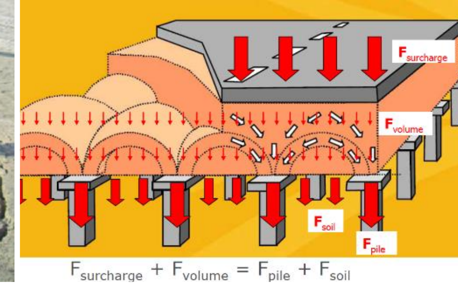
2. Behind the foundation concepts - back to the roots

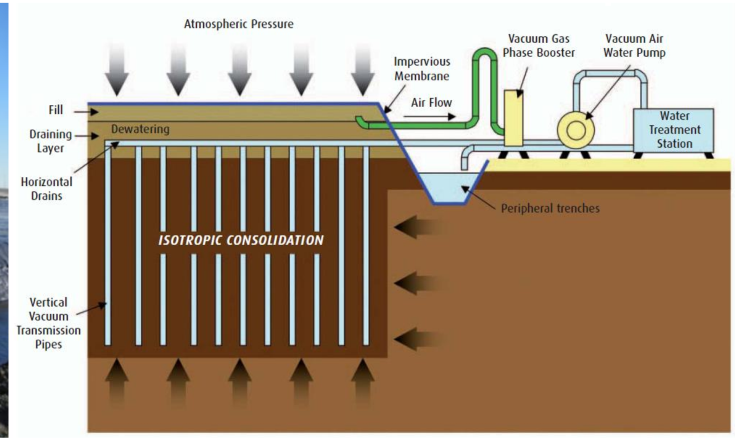
Difference between the classical foundation concepts

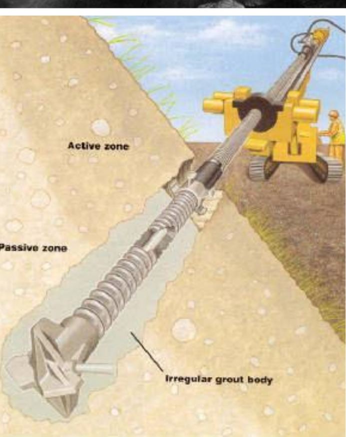


It is also possible to convert deep loose or soft soils to adequately competent soil by ground improvement




F surcharge
F volume
F soil
F pile
$F_{surcharge} + F_{volume} = F_{pile} + F_{soil}$


Atmospheric Pressure
Impervious Membrane
Vacuum Gas Phase Booster
Vacuum Air Water Pump
Air Flow
Water Treatment Station
Fill
Draining Layer
Dewatering
Horizontal Drains
Peripheral trenches
ISOTROPIC CONSOLIDATION
Vertical Vacuum Transmission Pipes


Active zone
Passive zone
Irregular grout body

2. Behind the foundation concepts - back to the roots

SIMSG ISSMGE

ICSMGE Alexandria 2009

17TH International Conference on Soil Mechanics & Geotechnical Engineering

State of the Art Report

Construction Processes

Procédés de Construction

Jian Chu
Nanyang Technological University, Singapore
Serge Varaksin
Menard, France
Ulrich Klotz
Zublin International GmbH, Germany
Patrick Mengé
Dredging International n.v., DEME, Belgium

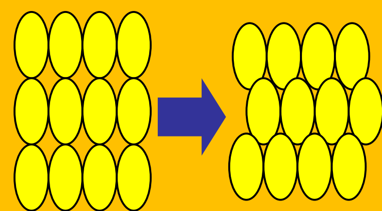
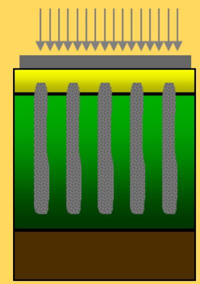
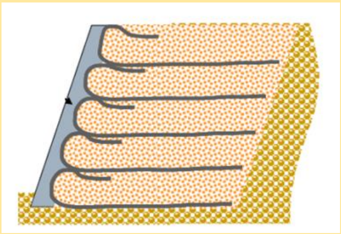
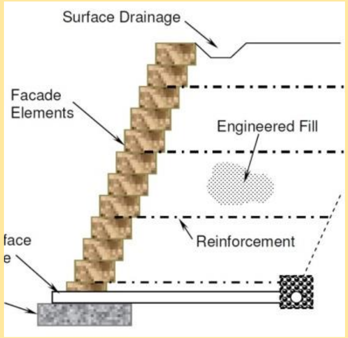
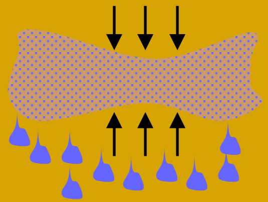
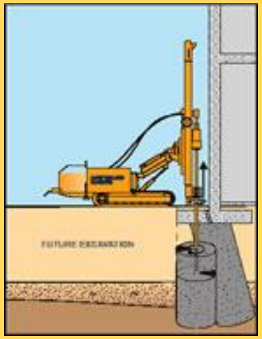
NOTA : TC 17 meeting ground improvement – 07/10/2009
Website : www.bbri.be/go/tc17

Table 1. Classification of ground improvement methods adopted by TC17

Category	Method	Principle
A. Ground improvement without admixtures in non-cohesive soils or fill materials	A1. Dynamic compaction	Densification of granular soil by dropping a heavy weight from air onto ground.
	A2. Vibrocompaction	Densification of granular soil using a vibratory probe inserted into ground.
	A3. Explosive compaction	Shock waves and vibrations are generated by blasting to cause granular soil ground to settle through liquefaction or compaction.
	A4. Electric pulse compaction	Densification of granular soil using the shock waves and energy generated by electric pulse under ultra-high voltage.
	A5. Surface compaction (including rapid impact compaction).	Compaction of fill or ground at the surface or shallow depth using a variety of compaction machines.
B. Ground improvement without admixtures in cohesive soils (also see Table 4)	B1. Replacement/displacement (including load reduction using light weight materials)	Remove bad soil by excavation or displacement and replace it by good soil or rocks. Some light weight materials may be used as backfill to reduce the load or earth pressure.
	B2. Preloading using fill (including the use of vertical drains)	Fill is applied and removed to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B3. Preloading using vacuum (including combined fill and vacuum)	Vacuum pressure of up to 90 kPa is used to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B4. Dynamic consolidation with enhanced drainage (including the use of vacuum)	Similar to dynamic compaction except vertical or horizontal drains (or together with vacuum) are used to dissipate pore pressures generated in soil during compaction.
	B5. Electro-osmosis or electro-kinetic consolidation	DC current causes water in soil or solutions to flow from anodes to cathodes which are installed in soil.
	B6. Thermal stabilisation using heating or freezing	Change the physical or mechanical properties of soil permanently or temporarily by heating or freezing the soil.
	B7. Hydro[illegible]sting compaction	Collapsible so[illegible] (loess) is compacted [illegible] a [illegible]ned wetting and deep explosion [illegible]ctio[illegible] a [illegible]ho[illegible].
C. Ground improvement with admixtures or inclusions	C1. Vibro replacement or stone columns	Hole jetted into soft, fine-grained soil and back filled with densely compacted gravel or sand to form columns.
	C2. Dyna[illegible]t	[illegible]es ar[illegible] by high [illegible] impact to form columns. The [illegible] either sand, gravel, stones or [illegible]ebris.
	C3. Sand compaction piles	Sand is fed into ground through a casing pipe and compacted by either vibration, dynamic impact, or static excitation to form columns.
	C4. Geotextile confined columns	Sand is fed into a closed bottom geotextile lined cylindrical hole to form a column.
	C5. Rigid inclusions (or composite foundation, also see Table 5)	Use of piles, rigid or semi-rigid bodies or columns which are either premade or formed in-situ to strengthen soft ground.
	C6. Geosynthetic reinforced column or pile supported embankment	Use of piles, rigid or semi-rigid columns/inclusions and geosynthetic girds to enhance the stability and reduce the settlement of embankments.
	C7. Microbial methods	Use of microbial materials to modify soil to increase its strength or reduce its permeability.
	C8 Other methods	Unconventional methods, such as formation of sand piles using blasting and the use of bamboo, timber and other natural products.
D. Ground improvement with grouting type admixtures	D1. Particulate grouting	Grout granular soil or cavities or fissures in soil or rock by injecting cement or other particulate grouts to either increase the strength or reduce the permeability of soil or ground.
	D2. Chemical grouting	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate to either increase the strength or reduce the permeability of soil or ground.
	D3. Mixing methods (including premixing or deep mixing)	Treat the weak soil by mixing it with cement, lime, or other binders in-situ using a mixing machine or before placement
	D4. Jet grouting	High speed jets at depth erode the soil and inject grout to form columns or panels
	D5. Compaction grouting	Very stiff, mortar-like grout is injected into discrete soil zones and remains in a homogenous mass so as to densify loose soil or lift settled ground.
	D6. Compensation grouting	Medium to high viscosity particulate suspensions is injected into the ground between a subsurface excavation and a structure in order to negate or reduce settlement of the structure due to ongoing excavation.
E. Earth reinforcement	E1. Geosynthetics or mechanically stabilised earth (MSE)	Use of the tensile strength of various steel or geosynthetic materials to enhance the shear strength of soil and stability of roads, foundations, embankments, slopes, or retaining walls.
	E2. Ground anchors or soil nails	Use of the tensile strength of embedded nails or anchors to enhance the stability of slopes or retaining walls.
	E3. Biological methods using vegetation	Use of the roots of vegetation for stability of slopes.

Classification of the execution processes

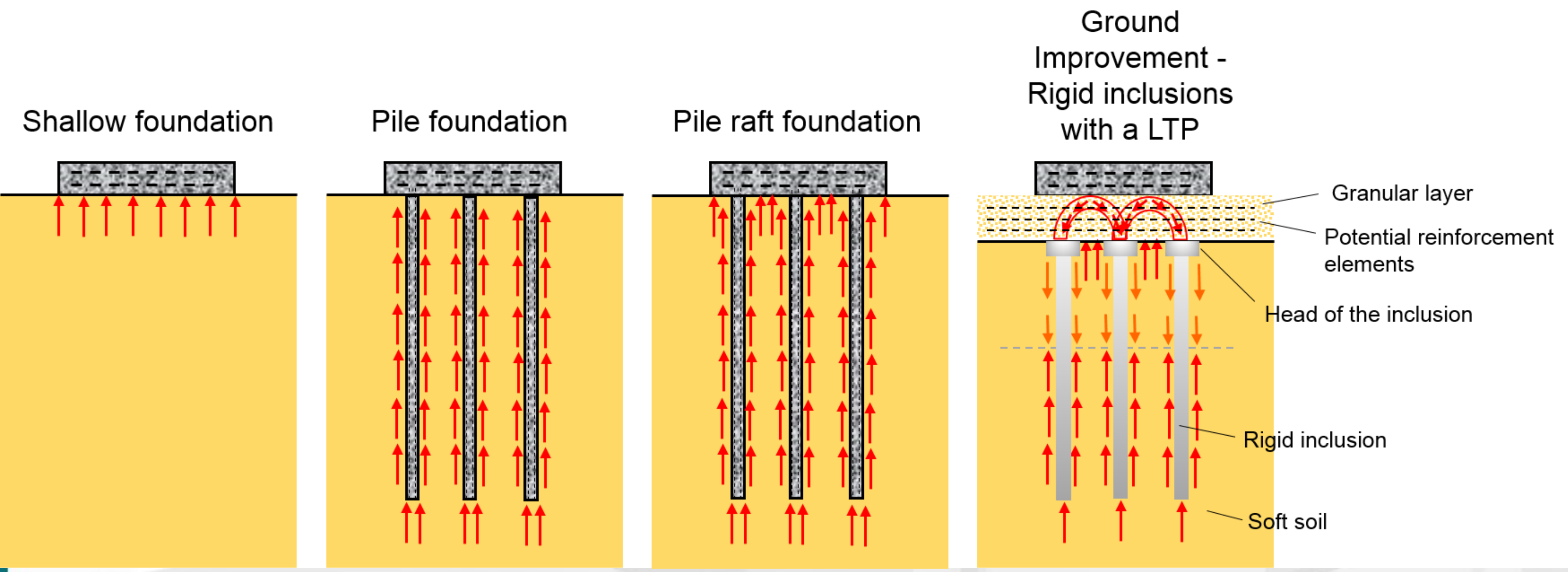
2. Behind the foundation concepts - back to the roots

Categories of GI methods	**Without admixture**	**With admixture**	**Soil reinforcement – in fill and in cut**
Cohesionless soil – **Non-cohesive soil –** **Granular soil –** **(sand, fill material)**	**Dynamic consolidation** **Vibrocompaction…**  A	**Rigid inclusions** **Stone columns**  C	**Geosynthetics** **MSE walls** **Anchors and nails**   E
Cohesive soil **(peat, clay…)**	**Preloading** **Vertical drains** **Vacuum consolidation…**  B	**Jet grouting** **Deep soil mixing…**  D	

2. Behind the foundation concepts - back to the roots

Concept of rigid inclusions

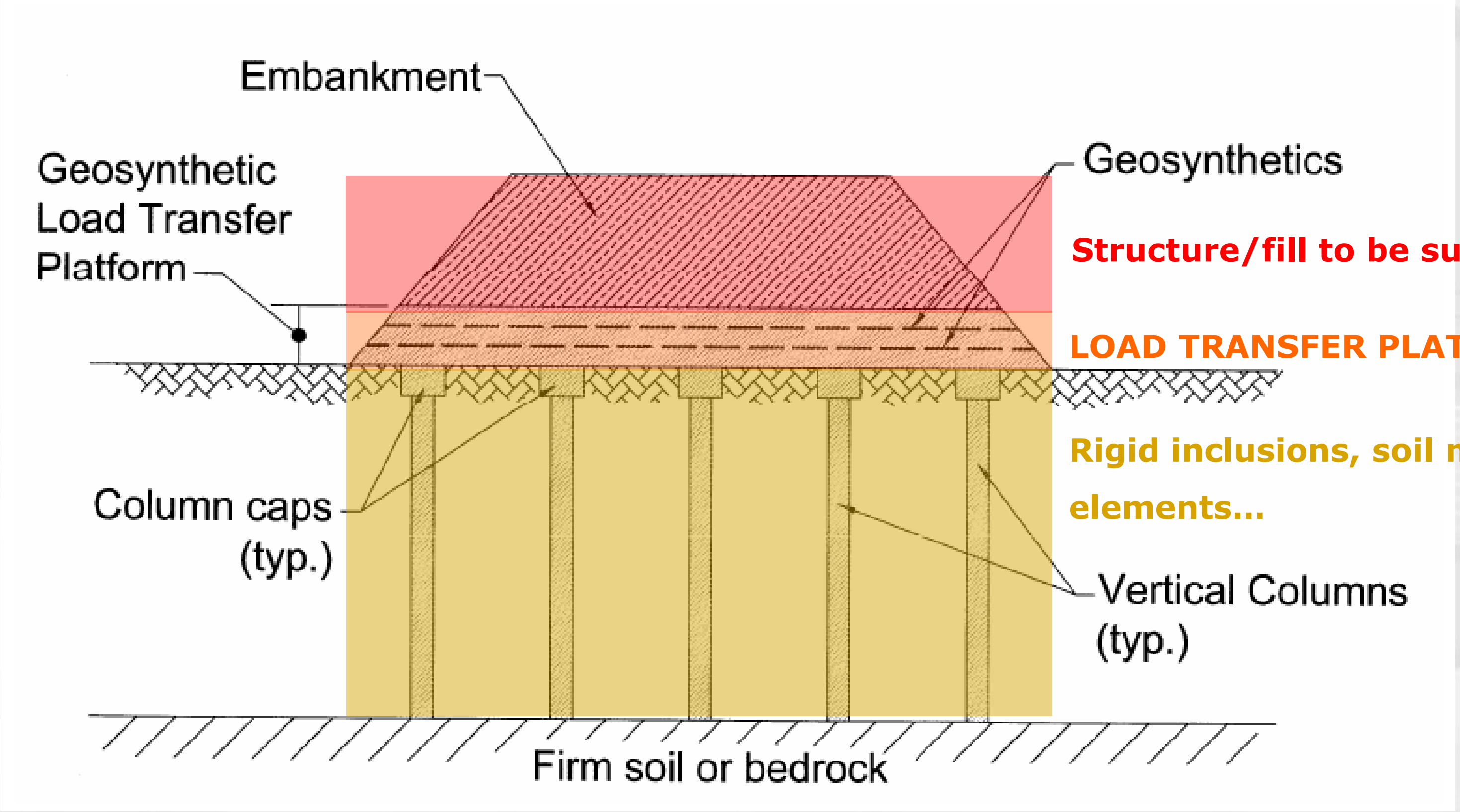
"It looks like a pile… but it's not a pile!"



The rigid inclusions combined with a load transfer platform cannot be designed (or considered) as piles

3. Ground improvement by rigid inclusions

Principles of the rigid inclusions and the load transfer platform (LTP) - principles



3. Ground improvement by rigid inclusions

Principles of the rigid inclusions and the load transfer platform (LTP) – main reference

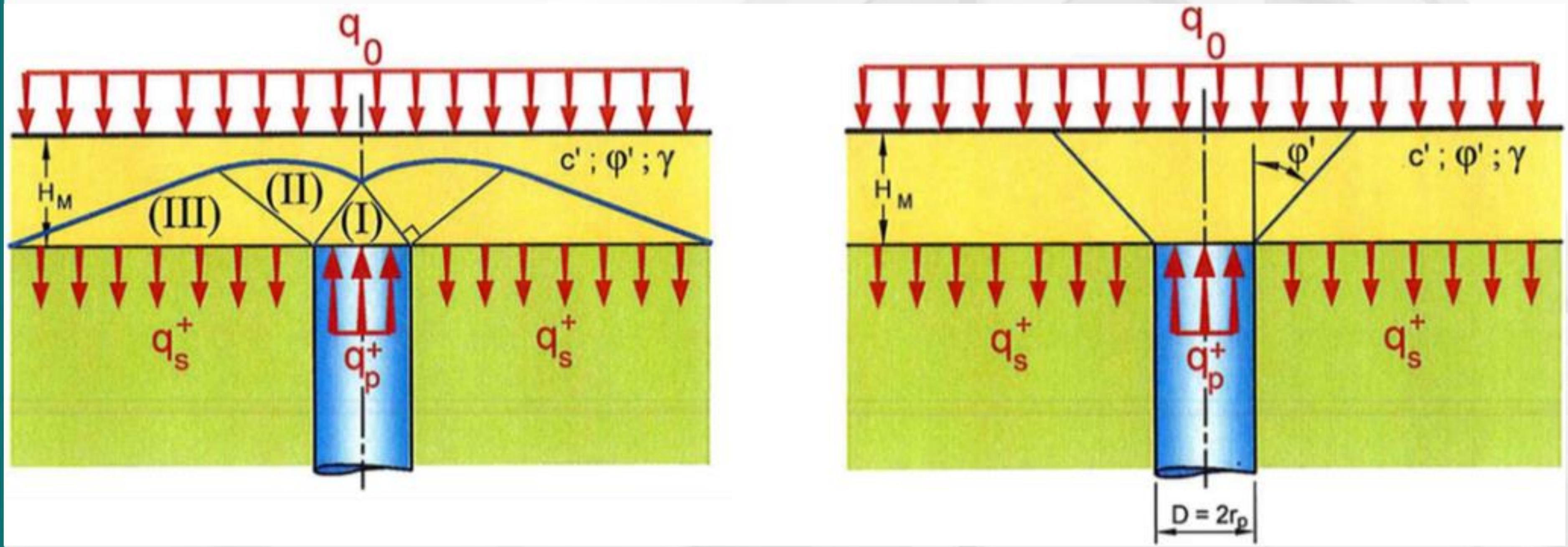
ASIRI guidelines - IREX (2012)

in line with the Eurocodes

3. Ground improvement by rigid inclusions

Failure mechanisms developing in the LTP

Prandtl's failure mechanism | **Punching shear failure mechanism**



Thick embankment

Thin embankment

q_0 = Uniformly distributed external load applied LTP
q_p^+ = stress on the inclusion head
q_s^+ = stress on the *in-situ* soil

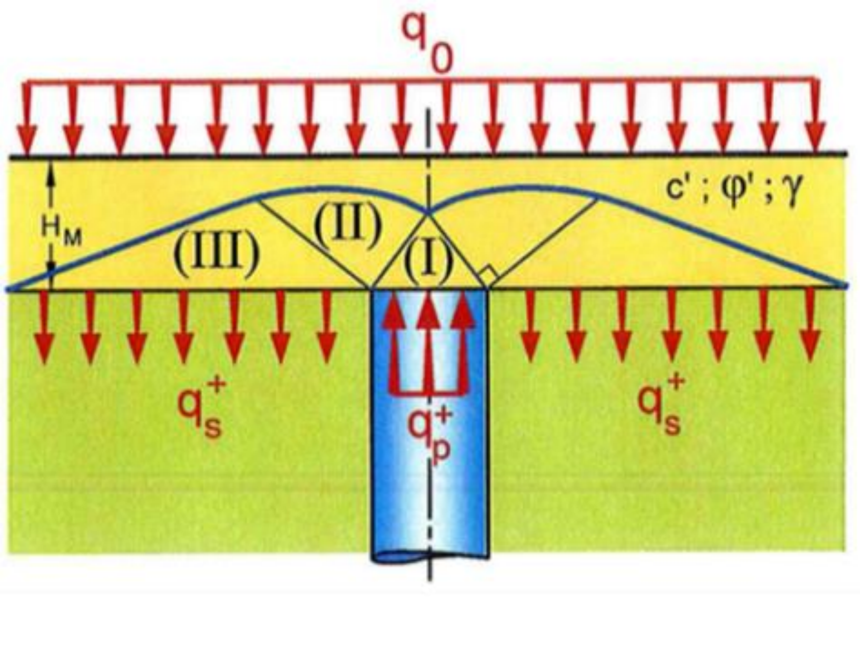
$$H_M < 0.7(s - D)$$

s = center to center spacing of the square grid

3. Ground improvement by rigid inclusions

Failure mechanisms developing in the LTP

Prandtl's failure mechanism



Determination of q_p^+ and q_s^+

Prandtl's equation:

$$q_p{}^+ = N_q q_s{}^+ \qquad \text{(equation 1a)}$$

Load conservation equation:

$$\alpha q_p{}^+ + (1-\alpha) q_s{}^+ = q_o \qquad \text{(equation 4)}$$

→ α is the replacement ratio

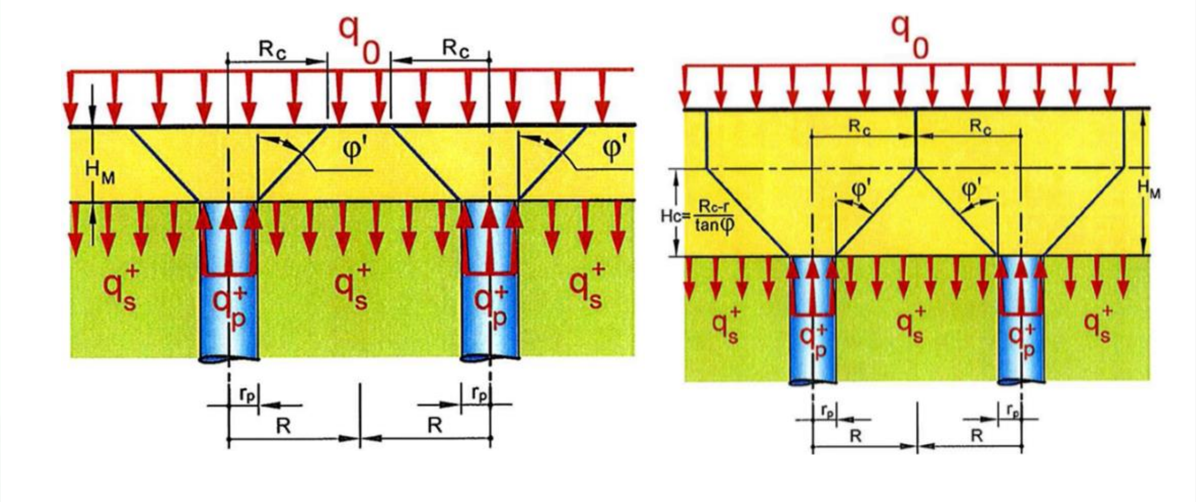
$$q_p{}^+ = \frac{N_q}{1+\alpha\left(N_q - 1\right)} q_o$$

$$q_s{}^+ = \frac{1}{1+\alpha\left(N_q - 1\right)} q_o$$

3. Ground improvement by rigid inclusions

Failure mechanisms developing in the LTP

Punching shear failure mechanisms (thin embankment) $H_M < 0.7(s - D)$



Non-overlapping failure cones ($H_M<H_c$)

Overlapping failure cones ($H_M>H_c$)

$$H_c = \frac{R - r_p}{\tan\varphi'}$$

$$R = \frac{s}{\sqrt{\pi}}$$

$$R_c = r_p + H_M \tan\left(\frac{\varphi'}{\gamma_{\varphi'}}\right)$$

$$q_p{}^+ = \frac{H_M}{3}\left(\frac{R_c{}^2}{r_p{}^2} + 1 + \frac{R_c}{r_p}\right)\frac{\gamma}{\gamma_\gamma} + \frac{R_c{}^2}{r_p{}^2}q_0 + \frac{1}{\tan\varphi'}\left(\frac{R_c{}^2}{r_p{}^2} - 1\right)\frac{c'}{\gamma_{c'}}$$

No overlap eq. (1b blue)

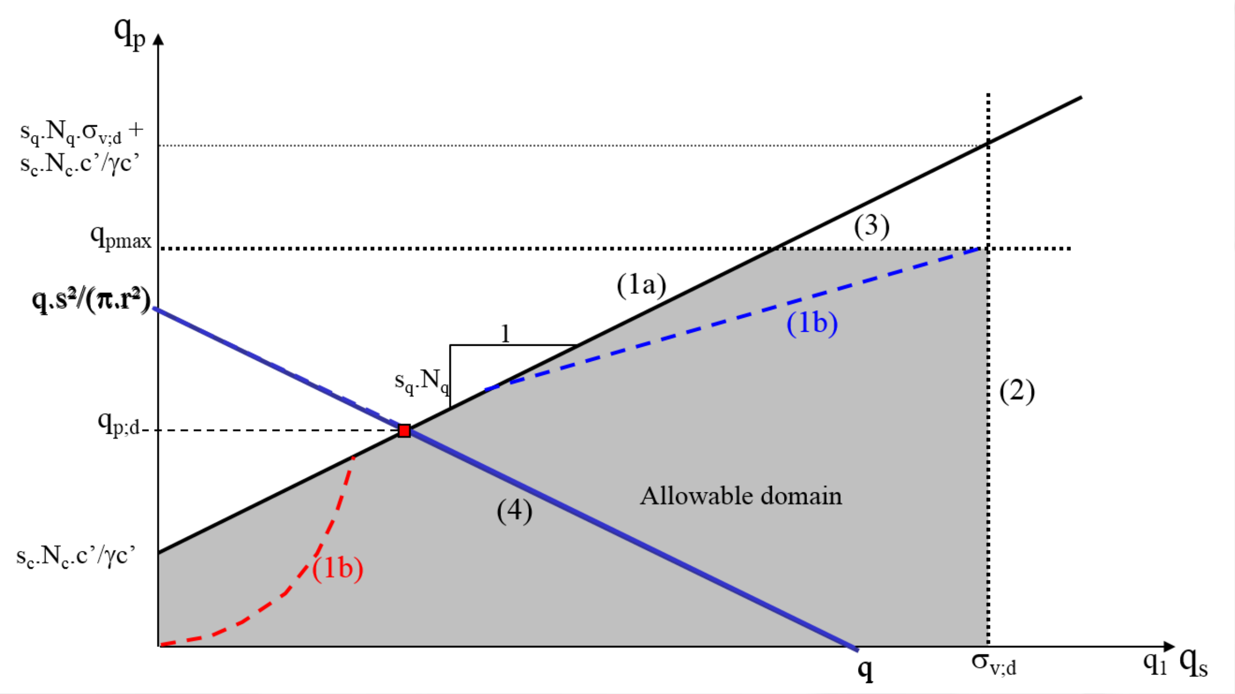
$$q_p{}^+ = \left[\frac{H_c}{3}\left(\frac{R^2}{r_p{}^2} + 1 + \frac{R}{r_p}\right) + (H_M - H_c)\frac{R^2}{r_p{}^2}\right]\frac{\gamma}{\gamma_\gamma} + \frac{R^2}{r_p{}^2}q_o + \left[\frac{1}{\tan\varphi'}\left(\frac{R^2}{r_p{}^2} - 1\right)\right]\frac{c'}{\gamma_{c'}}$$

Overlap eq. (1b red)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

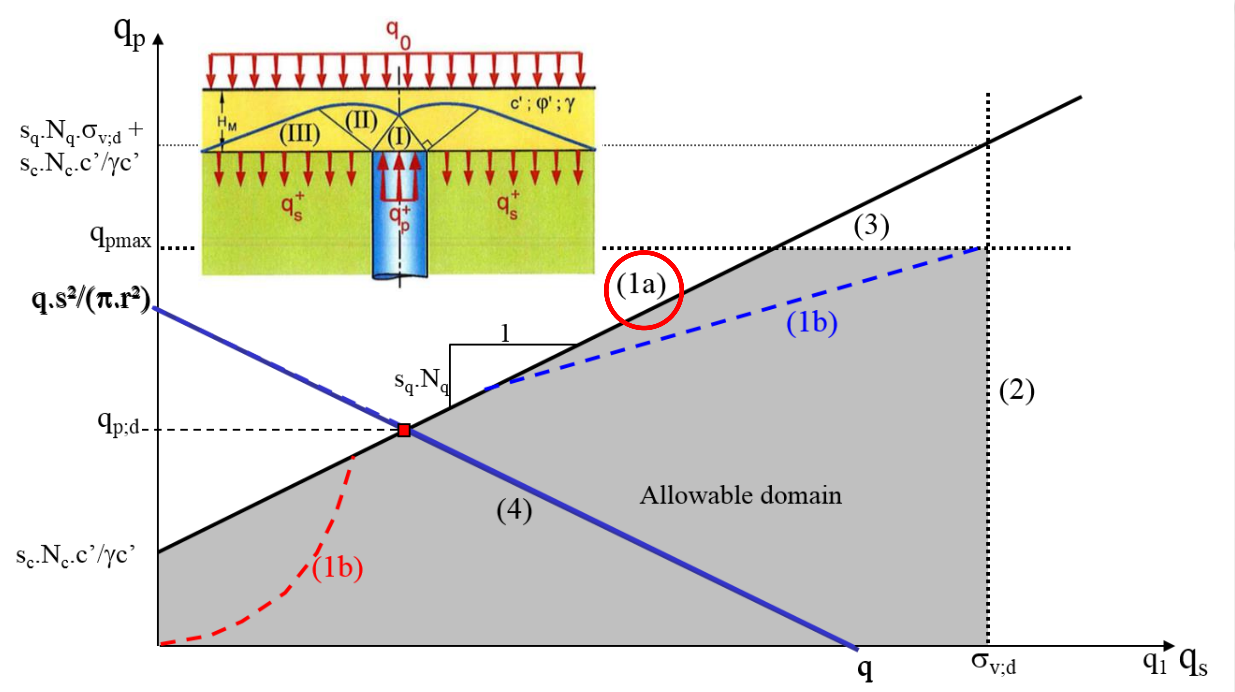
Domain of admissible stresses (ULS) at the base of the LTP



3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



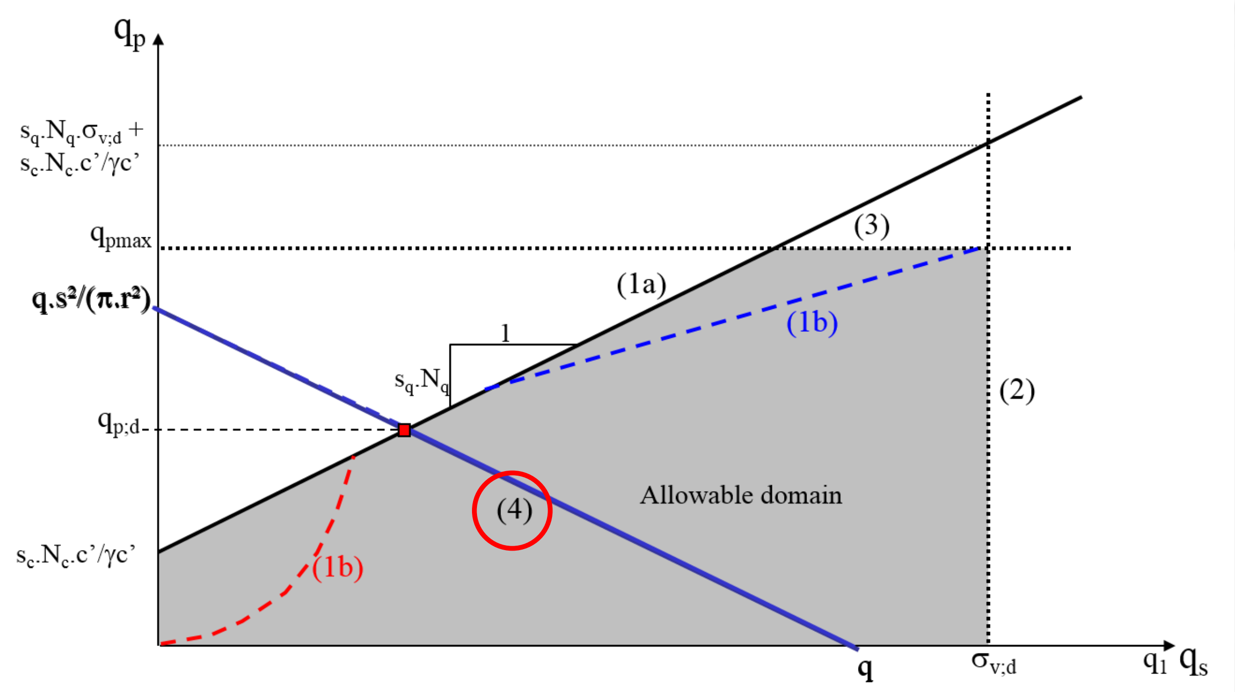
Prandtl's equation:

$$q_p{}^+ = N_q q_s{}^+ \qquad \text{(equation 1a)}$$

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



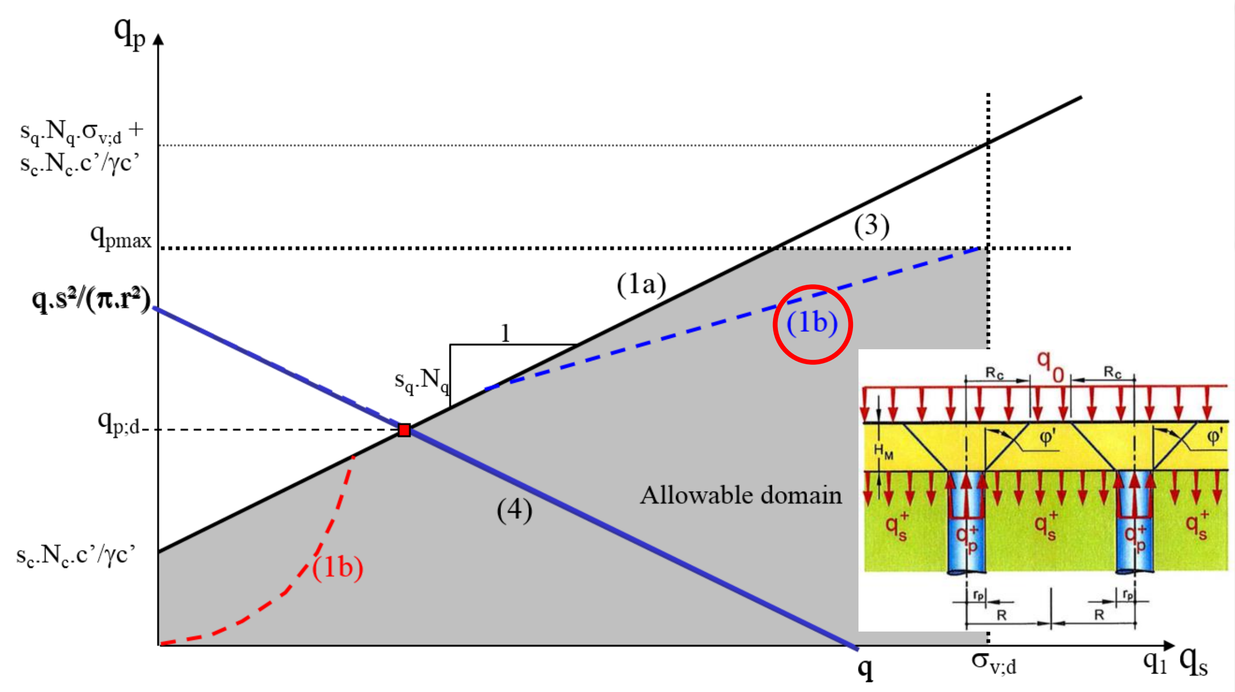
Load conservation equation:

$$\alpha {q_p}^{+} + (1-\alpha){q_s}^{+} = q_o$$ (equation 4)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



Punching shear failure mechanism:

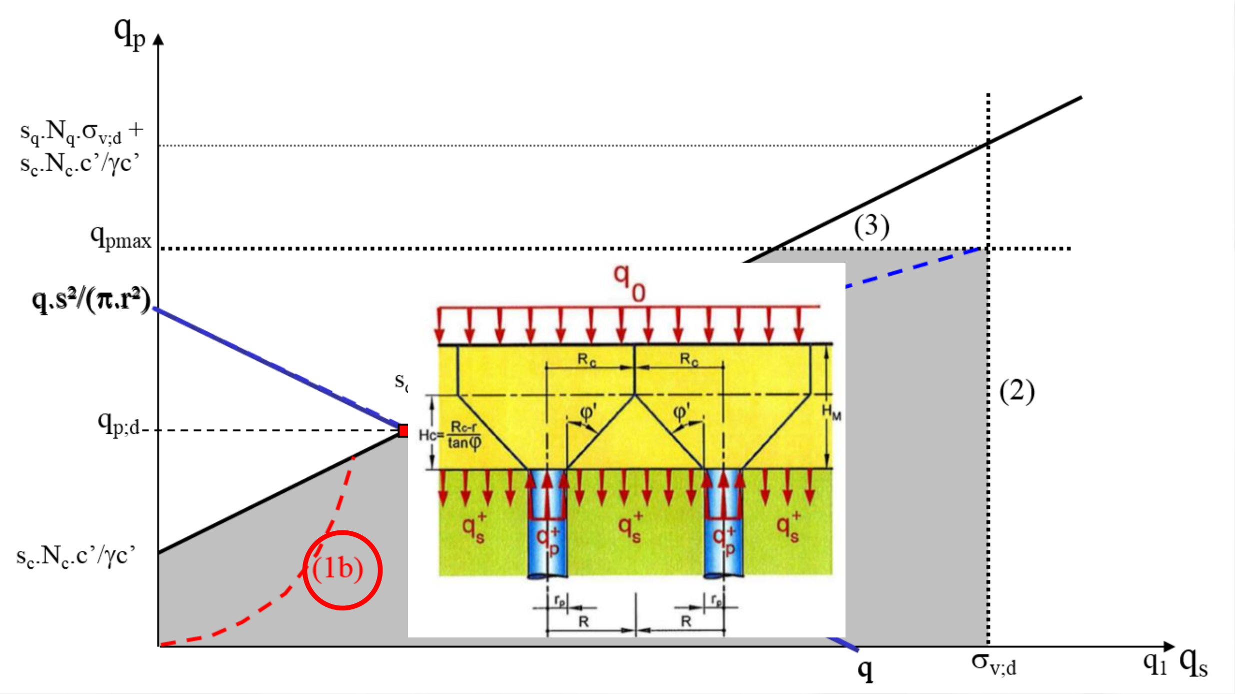
$$q_p{}^{+} = \frac{H_M}{3}\left(\frac{R_c{}^2}{r_p{}^2} + 1 + \frac{R_c}{r_p}\right)\frac{\gamma}{\gamma_\gamma} + \frac{R_c{}^2}{r_p{}^2}q_0 + \frac{1}{\tan\varphi'}\left(\frac{R_c{}^2}{r_p{}^2} - 1\right)\frac{c'}{\gamma_{c'}}$$

No overlap
eq. (1b blue)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



Punching shear failure mechanism:

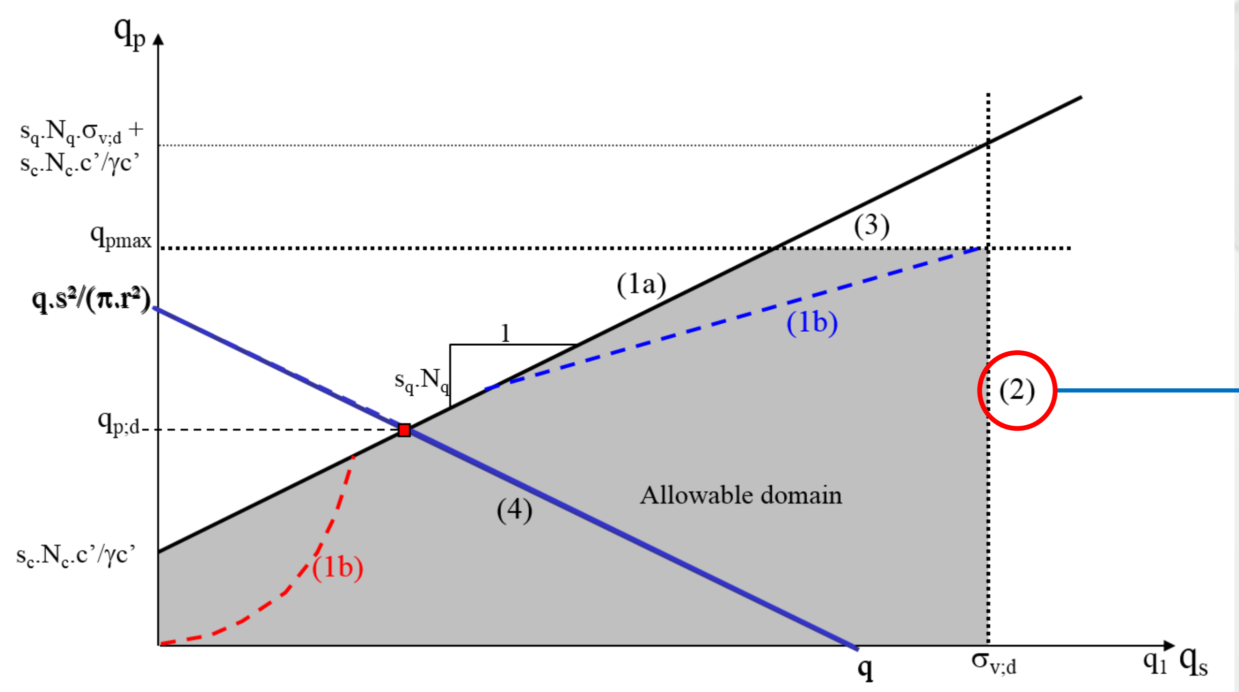
$$q_p{}^+ = \left[\frac{H_c}{3}\left(\frac{R^2}{r_p{}^2} + 1 + \frac{R}{r_p}\right) + (H_M - H_c)\frac{R^2}{r_p{}^2}\right]\frac{\gamma}{\gamma_\gamma} + \frac{R^2}{r_p{}^2}q_o + \left[\frac{1}{\tan\varphi'}\left(\frac{R^2}{r_p{}^2} - 1\right)\right]\frac{c'}{\gamma_{c'}}$$

Overlap eq. (1b red)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



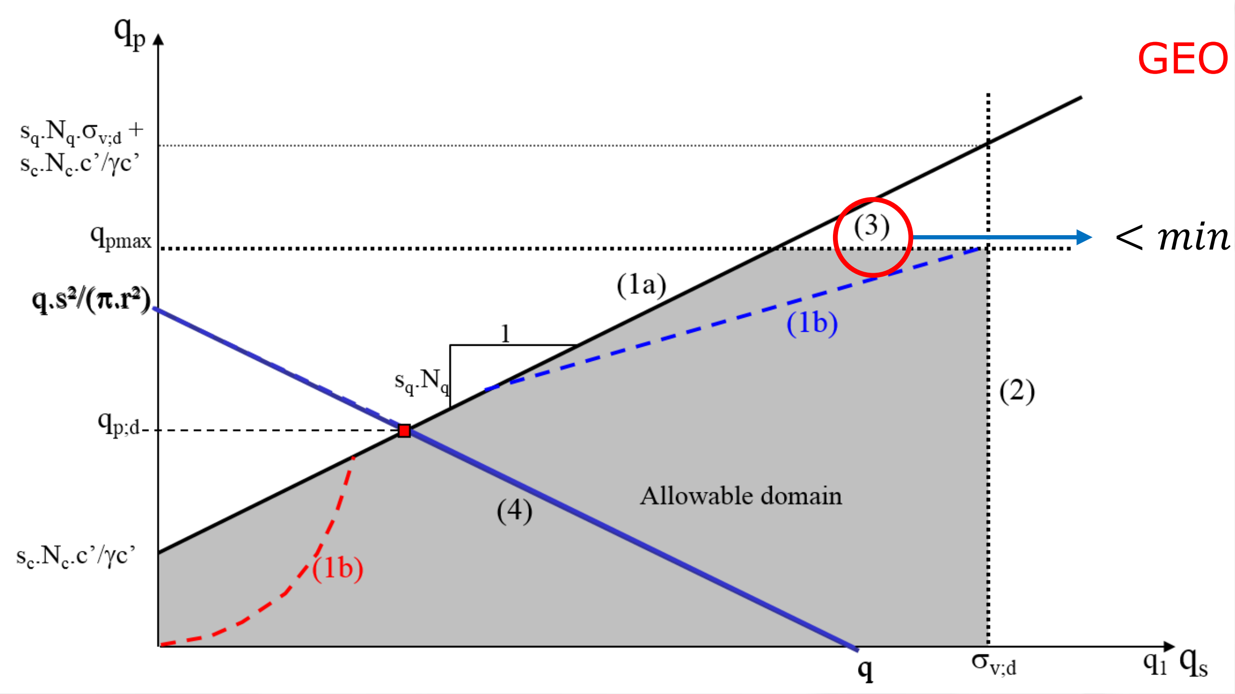
σ_{vd} → soil study (pressuremeter, penetrometer…)

$$\sigma_{v;d} = \frac{k_p P_{LM}}{\gamma_{R;v} \cdot \gamma_{R,d}}$$

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

Domain of admissible stresses (ULS) at the base of the LTP



GEO design

$$< min\left(\frac{R_b/\gamma_b.\gamma_{R,d} + R_s/\gamma_s.\gamma_{R,d}}{\pi r_p{}^2}; f_{c,d}\right)$$

STR design

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

GEO design of the rigid inclusion in line with Eurocode 7

→ **Axial compression behavior of the inclusion computed according to the principles of Eurocode 7 + NA**

SIMSG ISSMGE TC 211

WTCB

EEN UITGAVE VAN HET WETENSCHAPPELIJK EN TECHNISCH CENTRUM VOOR HET BOUWBEDRIJF

RAPPORT

RICHTLIJNEN VOOR DE TOEPASSING VAN DE EUROCODE 7 IN BELGIË

DEEL 1 : HET GRONDMECHANISCHE ONTWERP IN DE UITERSTE GRENSTOESTAND VAN AXIAAL OP DRUK BELASTE FUNDERINGSPALEN

WTCB-Rapport nr. 12 – 2009

Reef en ligne

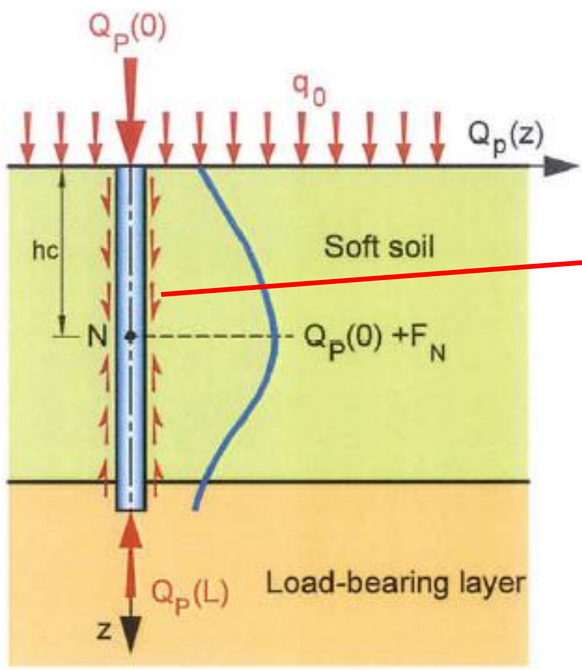
NF P94-262 (juillet 2012) : Justification des ouvrages géotechniques - Normes d'application nationale de l'Eurocode 7 - Fondations profondes (Indice de classement : P94-262)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

GEO design of the rigid inclusion in line with Eurocode 7

→ **Consideration of the negative skin friction**



$\tau < \sigma'_v K \tan\delta$

The negative skin friction is caused by the differential settlement (between the top of the inclusions and the granular layer of the LTP) also responsible for the arching effect in the LTP

$$F_N = 2\pi r_p \int_0^{hc} K \tan\delta \, \sigma'_v(z, r_p)\, dz$$

Combarieu (1974 and 1985)
NF P 94-262 (2012)

3. Ground improvement by rigid inclusions

ULS stress domain of the concept

STR design of the rigid inclusion

→ **Computation of $f_{c,d}$ = $UCS_{design\ value}$**

Methodologies available in the literature (detailed in the Keynote)

UCS= Uniaxial Compressive Strength

Detailed methodologies in line with the Eurocodes!

3. …gid inclusions

U… …ept

S…

…$_{c,d}$ = UCS$_{design\ value}$

…ature (detailed in the Keynote)

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1992-1-1

December 2004

ICS 91.010.30; 91.080.40

Supersedes ENV 1992-1-1:1991, ENV 1992-1-3:1994, ENV 1992-1-4:1994, ENV 1992-1-5:1994, ENV 1992-1-6:1994, ENV 1992-3:1998

English version

Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

Eurocode 2: Calcul des structures en béton - Partie 1-1 : Règles générales et règles pour les bâtiments

Eurocode 2: Bemessung und konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau

This European Standard was approved by CEN on 16 April 2004.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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cen

EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 1992-1-1:2004: E

Detailed methodologies in line with the Eurocodes!

3. … inclusions

U…

s…

= $UCS_{design\ value}$

e (detailed in the Keynote)


EUROPEAN STANDARD EN 1992-1-1

NORME…

EUROPÄ…

ICS 91.010.30…

Eurocode 2: C…
Règles g…

This European …

CEN members … Standard the st… standards may …

This European … under the respo… versions.

CEN members … Germany, Gree… Slovenia, Spain…

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Detailed methodologies in line with the Eurocodes!

3. ... clusions

U

S

EUROPEAN STANDARD

NORME

EUROPÄ

EN 1992-1-1

ICS 91.010.30

Eurocode 2: C
Règles g

This European

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CEN members
Germany, Gree
Slovenia, Spain

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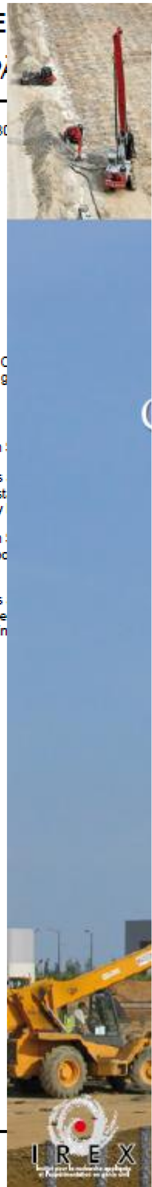
ASIRI NATIONAL PROJECT



DEUTSCHE NORM

August 2012

DIN 4093

DIN

ICS 93.020

Mit DIN EN 12715:2000-10
Ersatz für
DIN 4093:1987-09

Bemessung von verfestigten Bodenkörpern –
Hergestellt mit Düsenstrahl-, Deep-Mixing- oder Injektions-Verfahren

Design of ground improvement –
Jet grouting, deep mixing or grouting

Dimensionnement des renforcements de sol –
Colonnes de sol-ciment réalisées par jet, colonnes de sol traité ou injection

Gesamtumfang 18 Seiten

Normenausschuss Bauwesen (NABau) im DIN

CS$_{design\ value}$

etailed in the Keynote)

Detailed methodologies in line with the Eurocodes!

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3. ...clusions

U

S

...sign value

...ed in the Keynote)

Detailed methodologies in line with the Eurocodes!

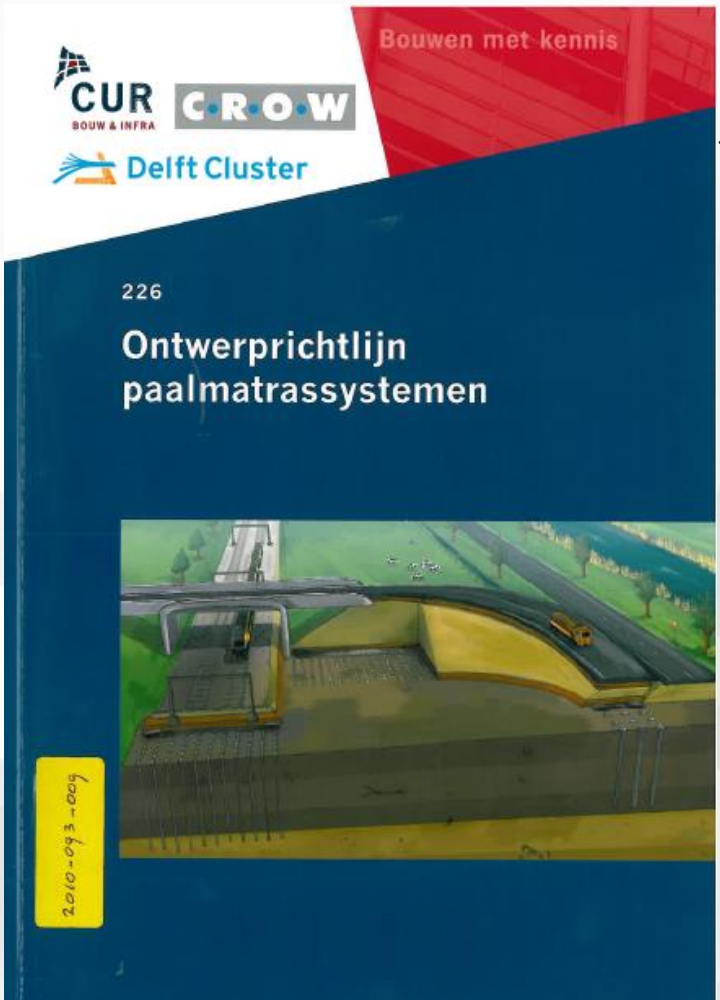
3. Ground improvement by rigid inclusions

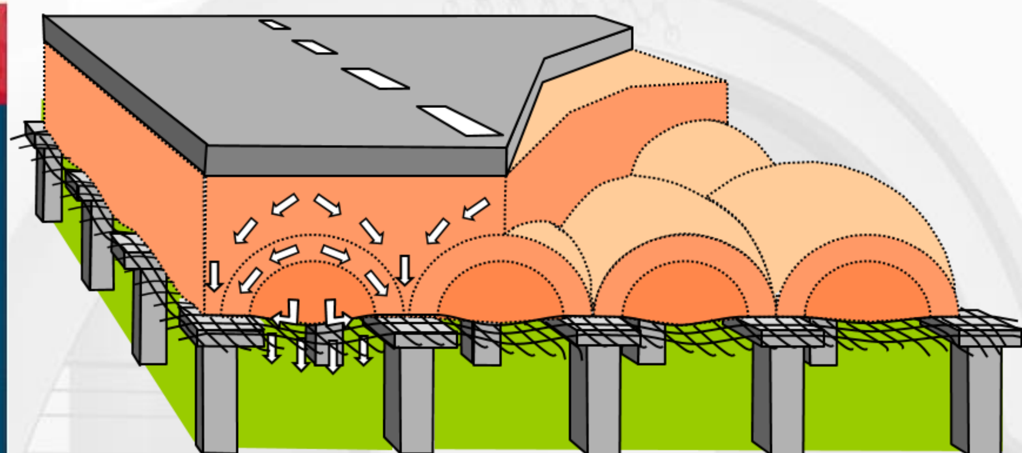
Other design aspects in ASIRI (IREX, 2012)

- **Stress distribution at the edge of the LTP**
- **SLS design approach**
- **Lateral loading**
  + lateral and flexural behavior of the rigid inclusions
- **Seismic loading**
- **Design of the foundation slabs on the LTP**
- **Design of the potential geosynthetics**
- **Numerical modeling**
- **Execution and QA/QC procedures**
- **Soil investigation and testing**
- **…**

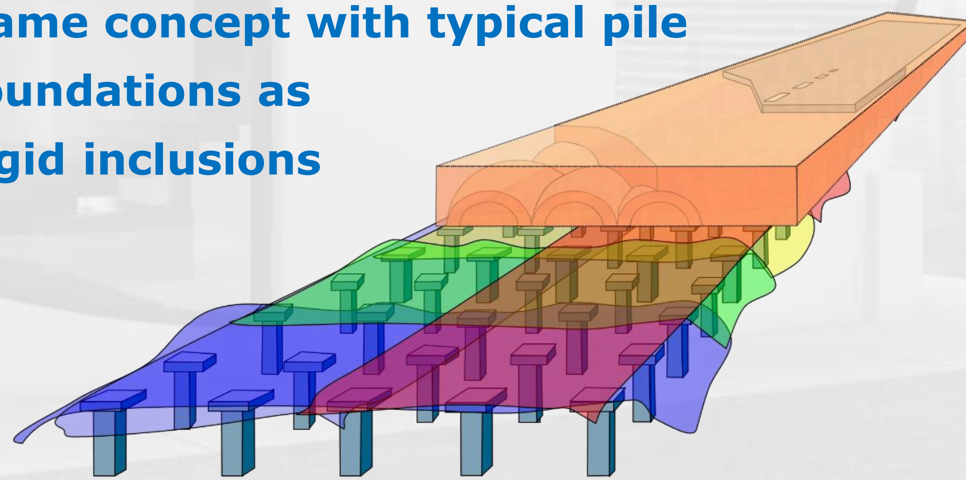
3. Ground improvement by rigid inclusions

Piled embankment – Dutch approach (CUR Rapport 226)





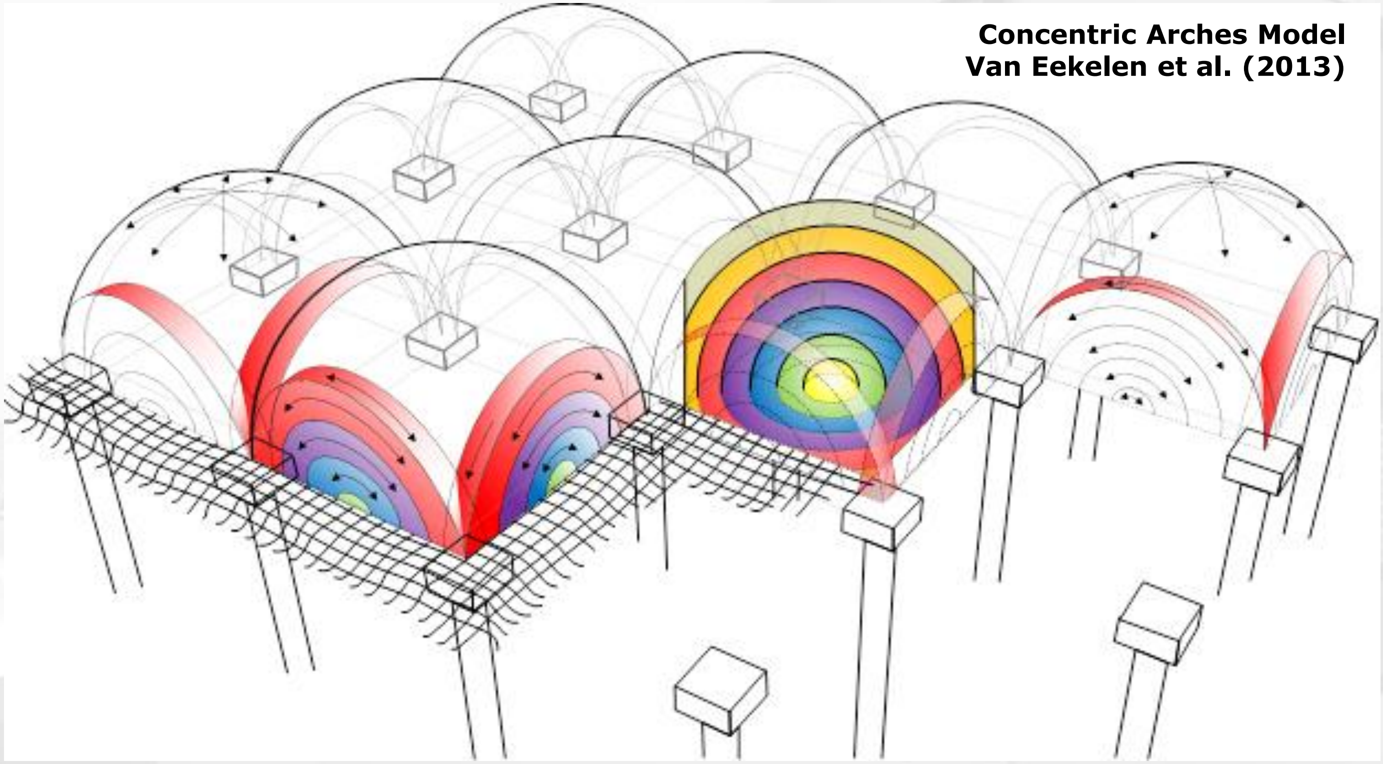
Same concept with typical pile foundations as rigid inclusions



3. Ground improvement by rigid inclusions

Piled embankment – Dutch approach (CUR Rapport 226)

Study of the load transfer distribution

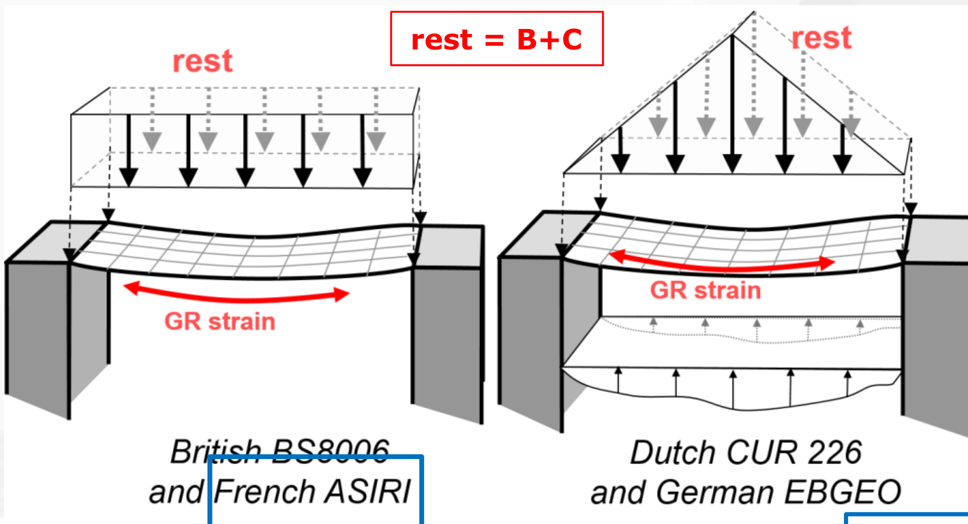


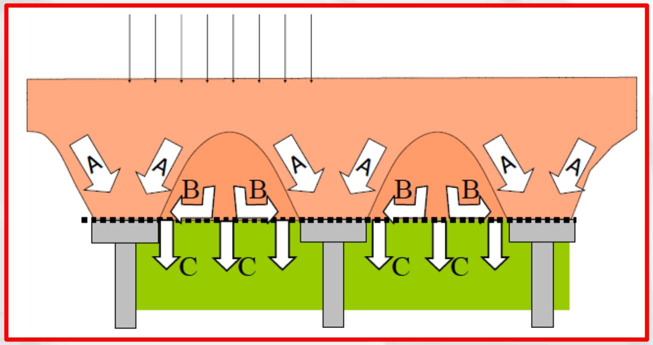
→ **Design of the geosynthetics at the base of the LTP**

3. Ground improvement by rigid inclusions

Piled embankment – Dutch approach (CUR Rapport 226)

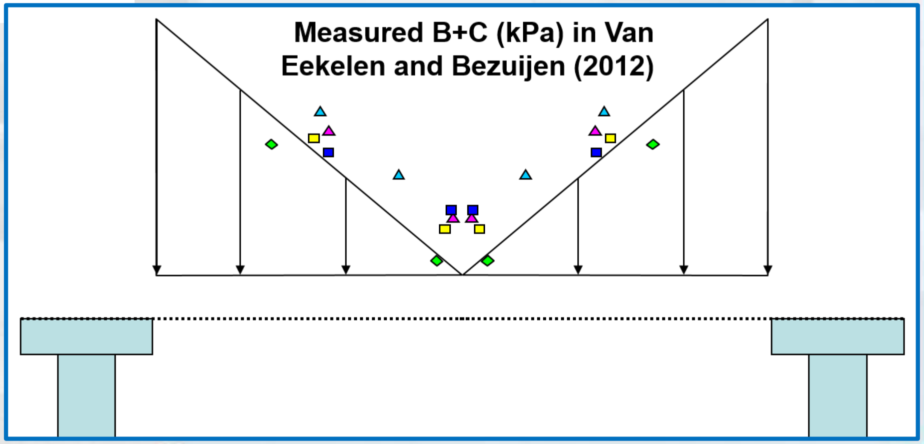
Study of the load transfer distribution





Load transfer distribution deduced from the Dutch in-situ and lab experiments

Uniform load transfer distribution used in the IREX (2012) – ASIRI guidelines

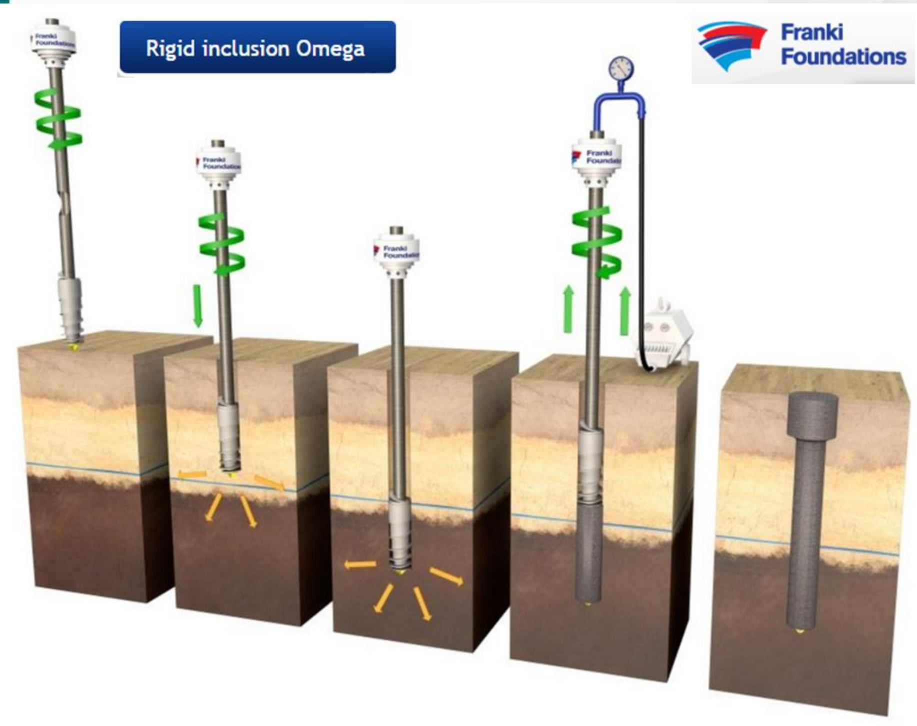


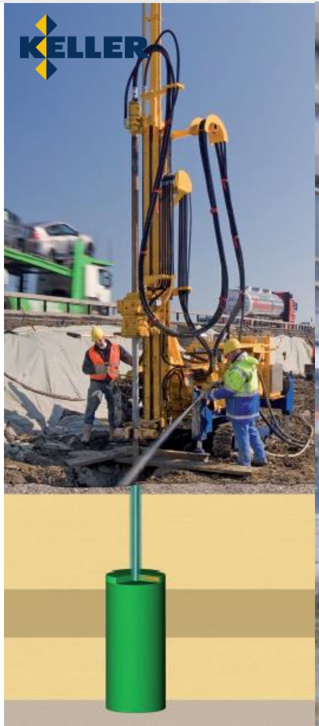
Research perspectives

3. Ground improvement by rigid inclusions

Execution methods - typical rigid inclusions

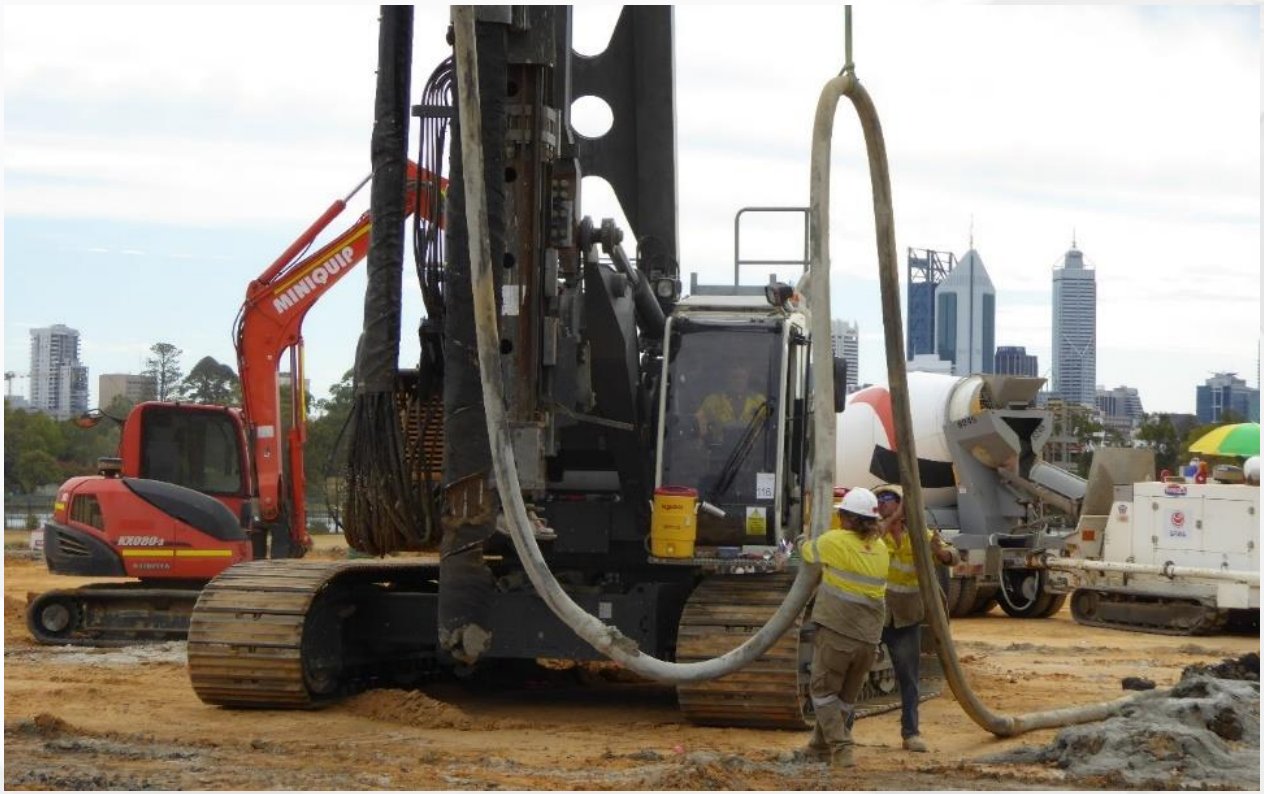
- Concrete columns - installed using (adapted) piling techniques
- Grout and jet grout columns
- Soil mix elements (columns, panels, trenches, blocks…)
- Controlled Modulus Columns (CMC)
- Grouted stone columns

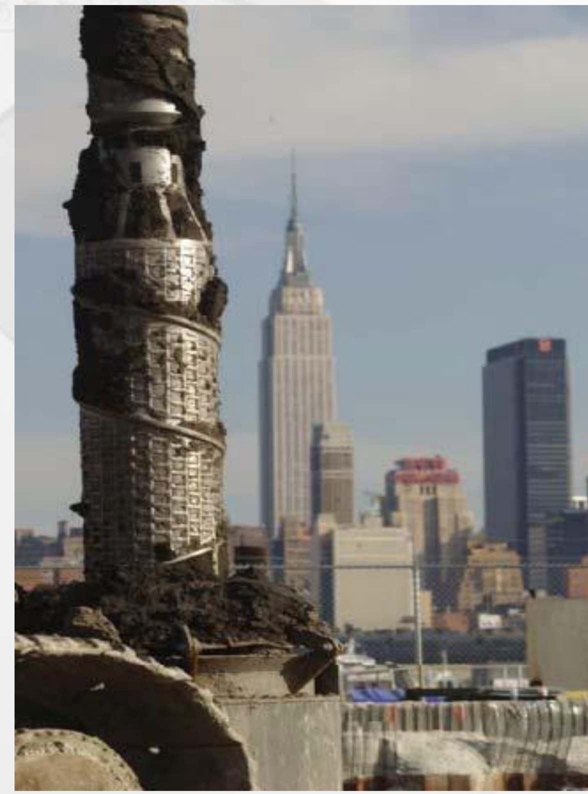




3. Ground improvement by rigid inclusions

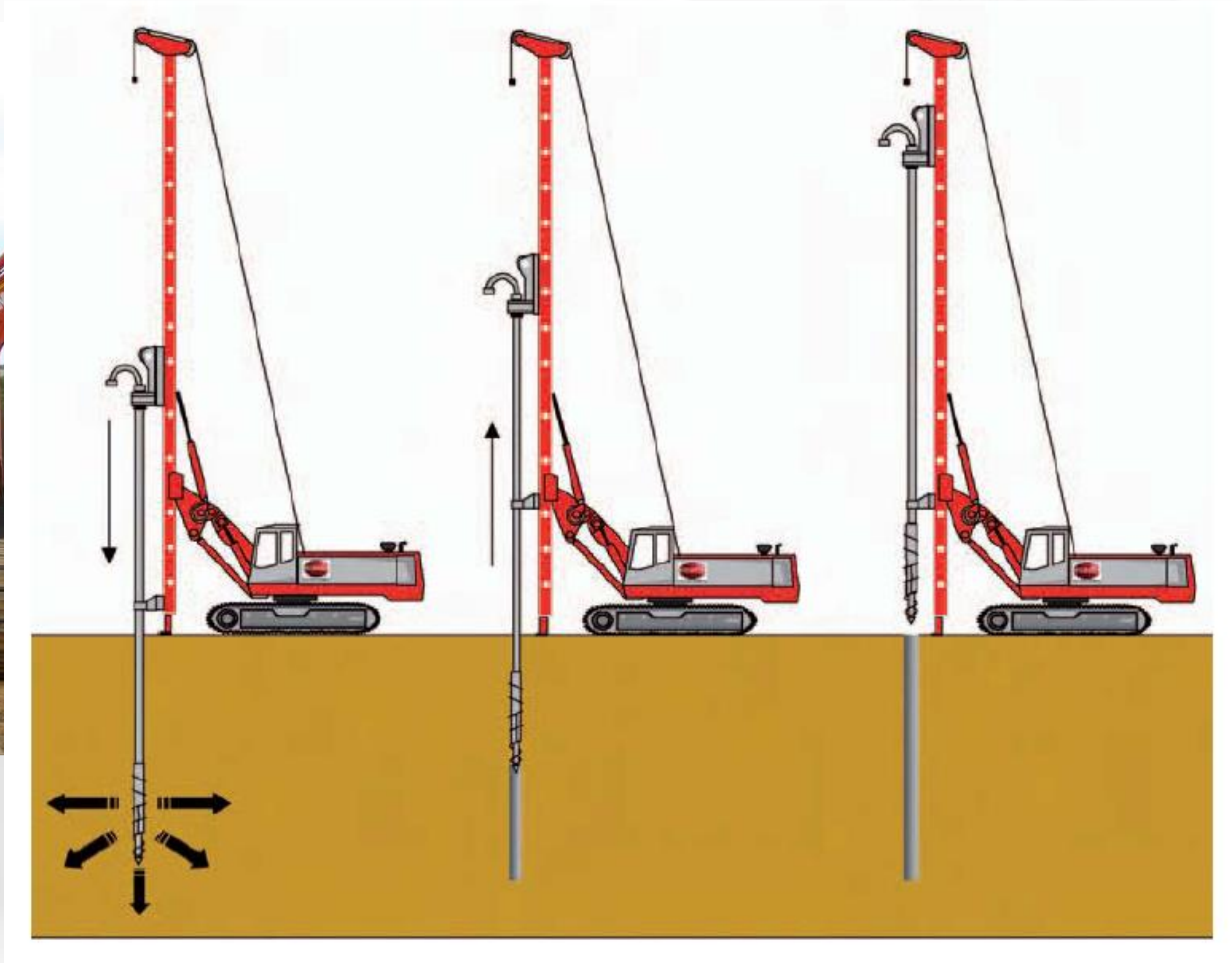
Execution methods – Illustration with the CMC process

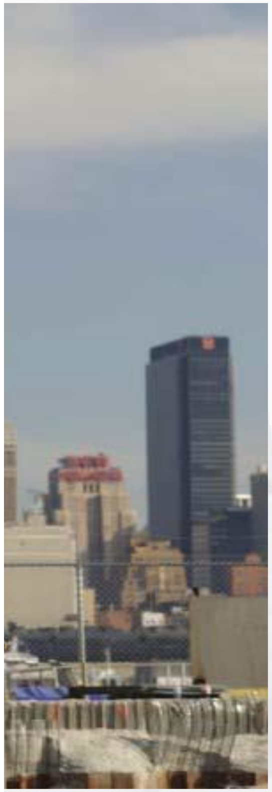




3. Ground improvement by rigid inclusions

Execution methods – Illustration with the CMC process





3. Ground improvement by rigid inclusions

Execution methods – Illustration with the CMC process

- **Column strength = grout strength**
- **High settlement reduction with lower replacement ratios**
- **Independent from external parameters for lateral stability**
- **Vibration free**
- **Negligible volumes of spoil**
- **High installation rates**
- **High installation depths**

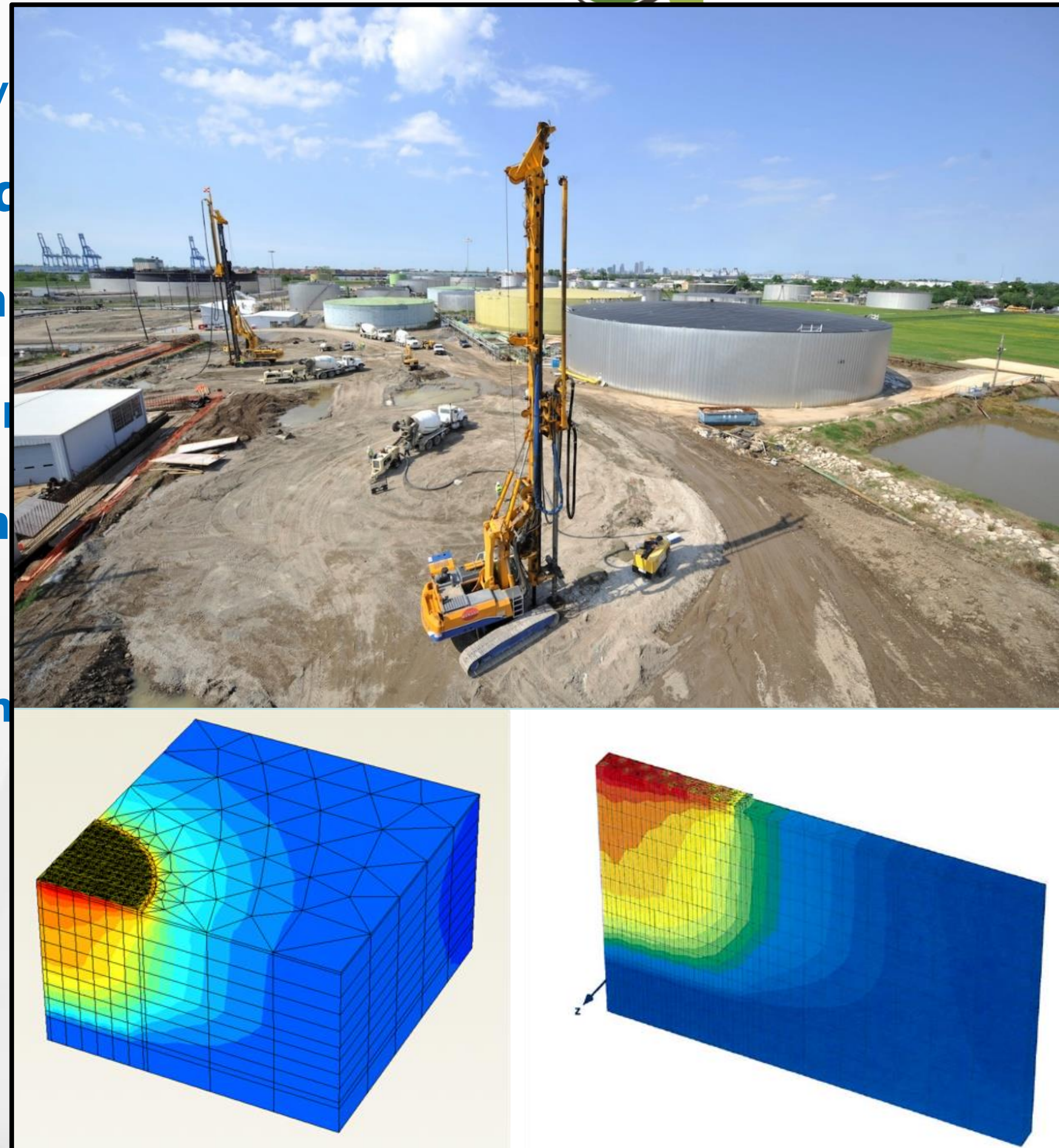
→ Case histories in the keynote

3. Ground improv

Execution methoc s

- Column strength
- High settlement
- Independent fro y
- Vibration free
- Negligible volum
- High installation
- High installation

→ Case histories in



Buschmeier et al. (2012)
Installation of
34 m long CMCs

Hamidi et al. (2016)
Installation of
42 m long CMCs
= world record!

Both in Louisiana State to support oil tanks

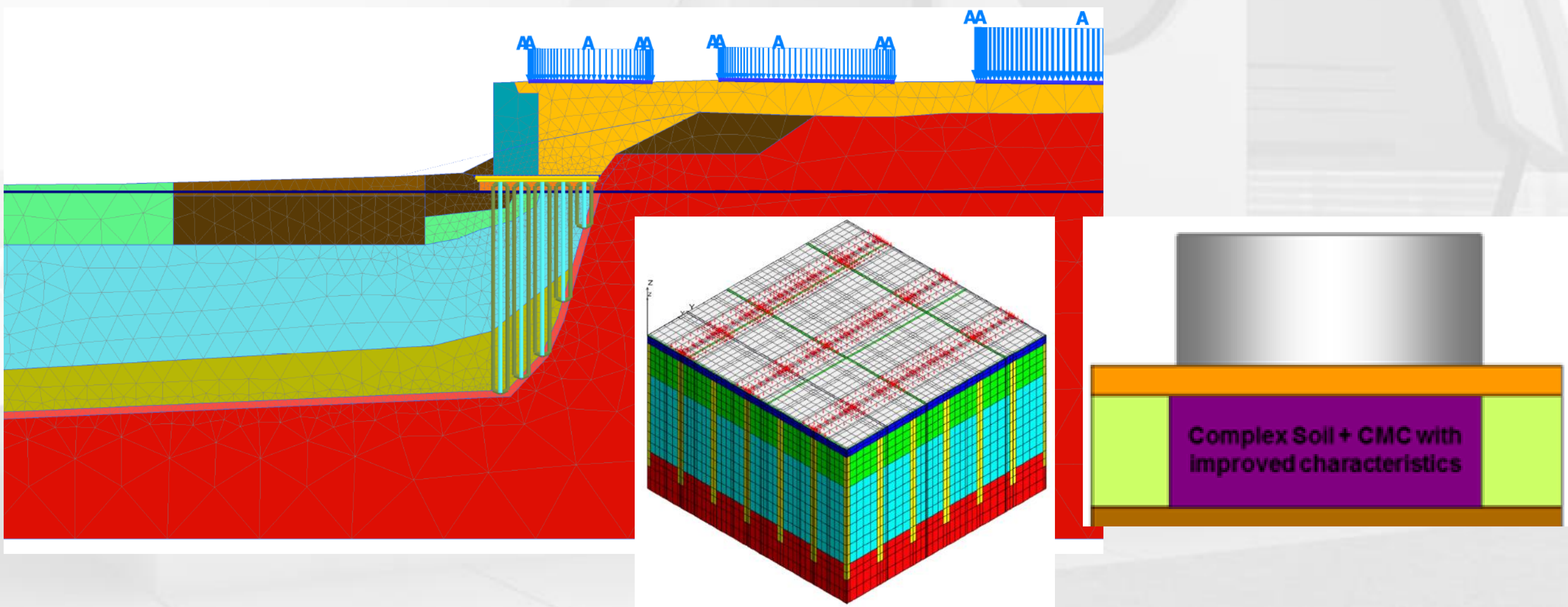
3. Ground improvement by rigid inclusions

Numerical modeling of rigid inclusions

ECSMGE 2015 - TC211 Workshop – J. Racinais

CALIBRATION OF RIGID INCLUSION PARAMETERS BASED ON PRESSUMETER TEST RESULTS

➢ **Global behavior of the reinforced soil**



3. Ground improvement by rigid inclusions

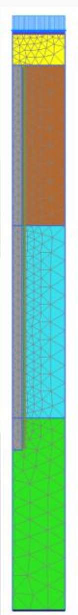
Numerical modeling of rigid inclusions

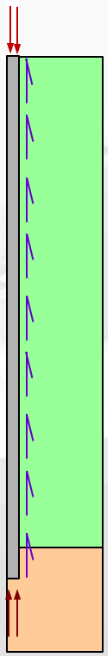
ECSMGE 2015 - TC211 Workshop – J. Racinais

CALIBRATION OF RIGID INCLUSION PARAMETERS BASED ON PRESSUMETER TEST RESULTS

➢ **Behavior of the rigid inclusions**

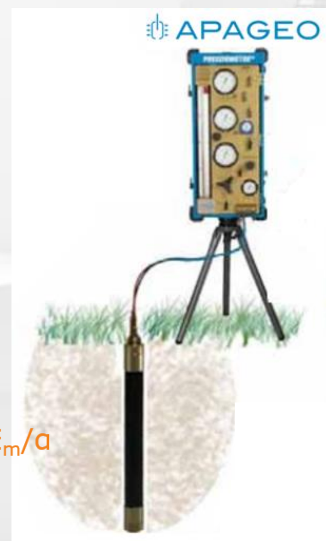
Calibration of FEM input parameters on Frank & Zhao's laws and on pressuremeter

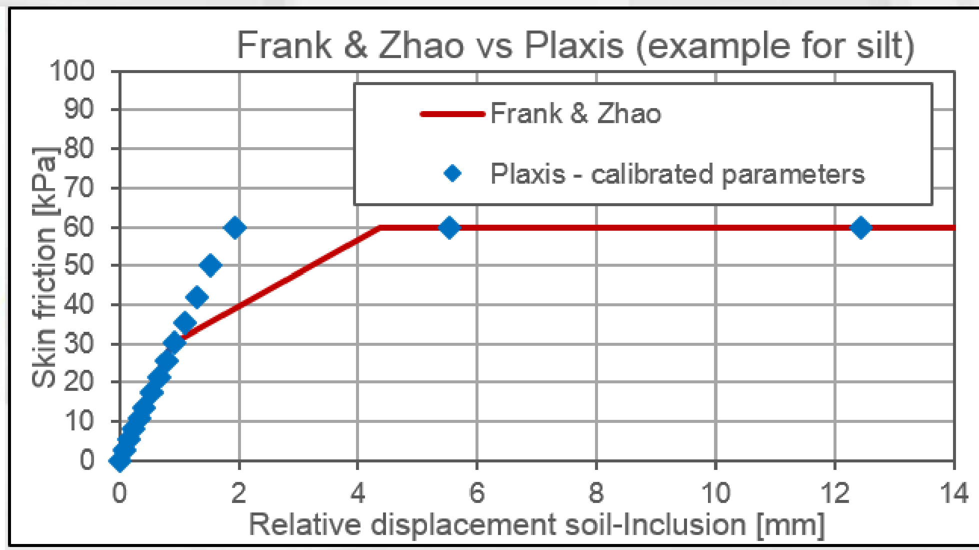




$E_Y = E_m/\alpha$
$c' = q_s$ (based on pressuremeter method)
$\varphi' \approx 0°$

E_Y = 1.5 to 6 x E_m/α
$c' = q_b/9$ (pressuremeter method), API (1991)
$\varphi' \approx 0°$





Along interface soil/inclusion

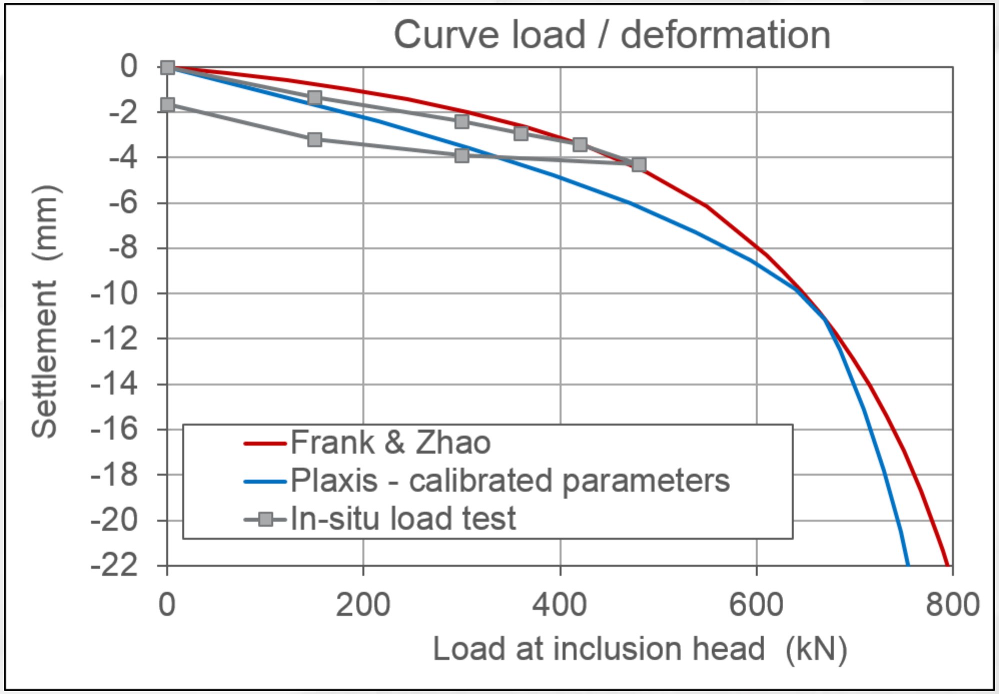
3. Ground improvement by rigid inclusions

Numerical modeling of rigid inclusions

ECSMGE 2015 - TC211 Workshop – J. Racinais

CALIBRATION OF RIGID INCLUSION PARAMETERS BASED ON PRESSUMETER TEST RESULTS

- **Validation with an in-situ load test**



4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Construction of an eleven-story building in Leuven (Belgium)

KU LEUVEN

REGA-Instituut (KU Leuven)
with the courtesy of SVR-Architects

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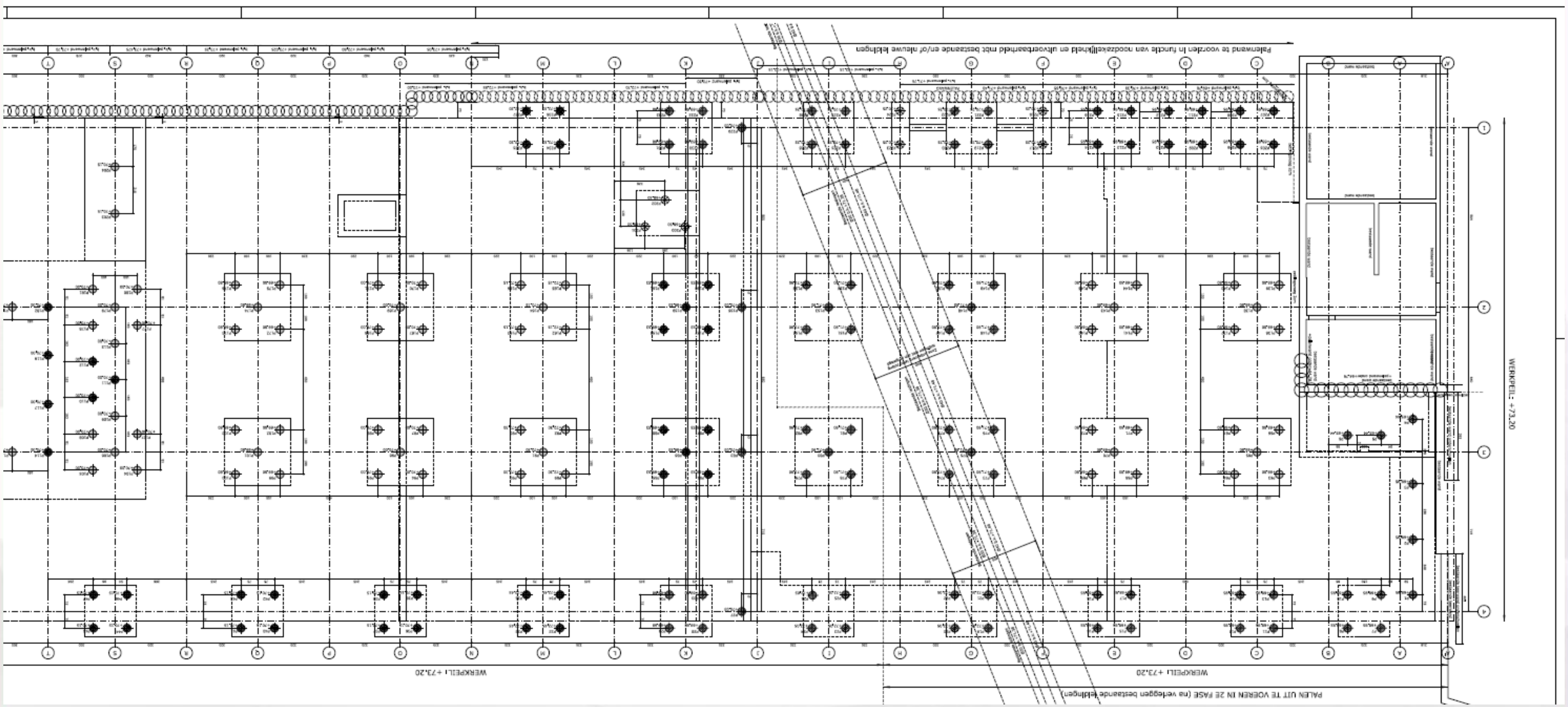
4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Original foundation plan with pile groups



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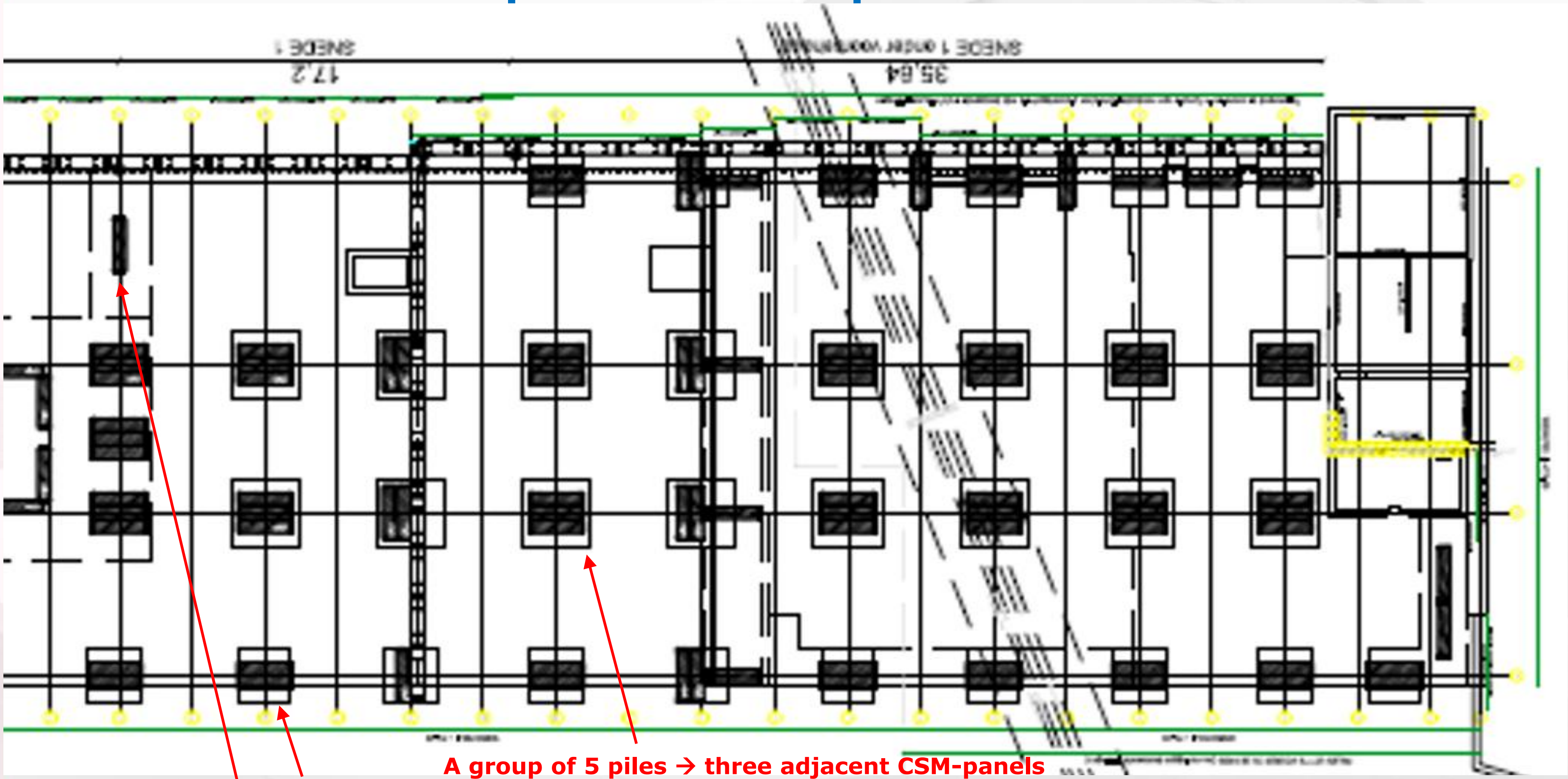
4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

New foundation plan with CSM-panels



4. Hybrid concept without load transfer platform

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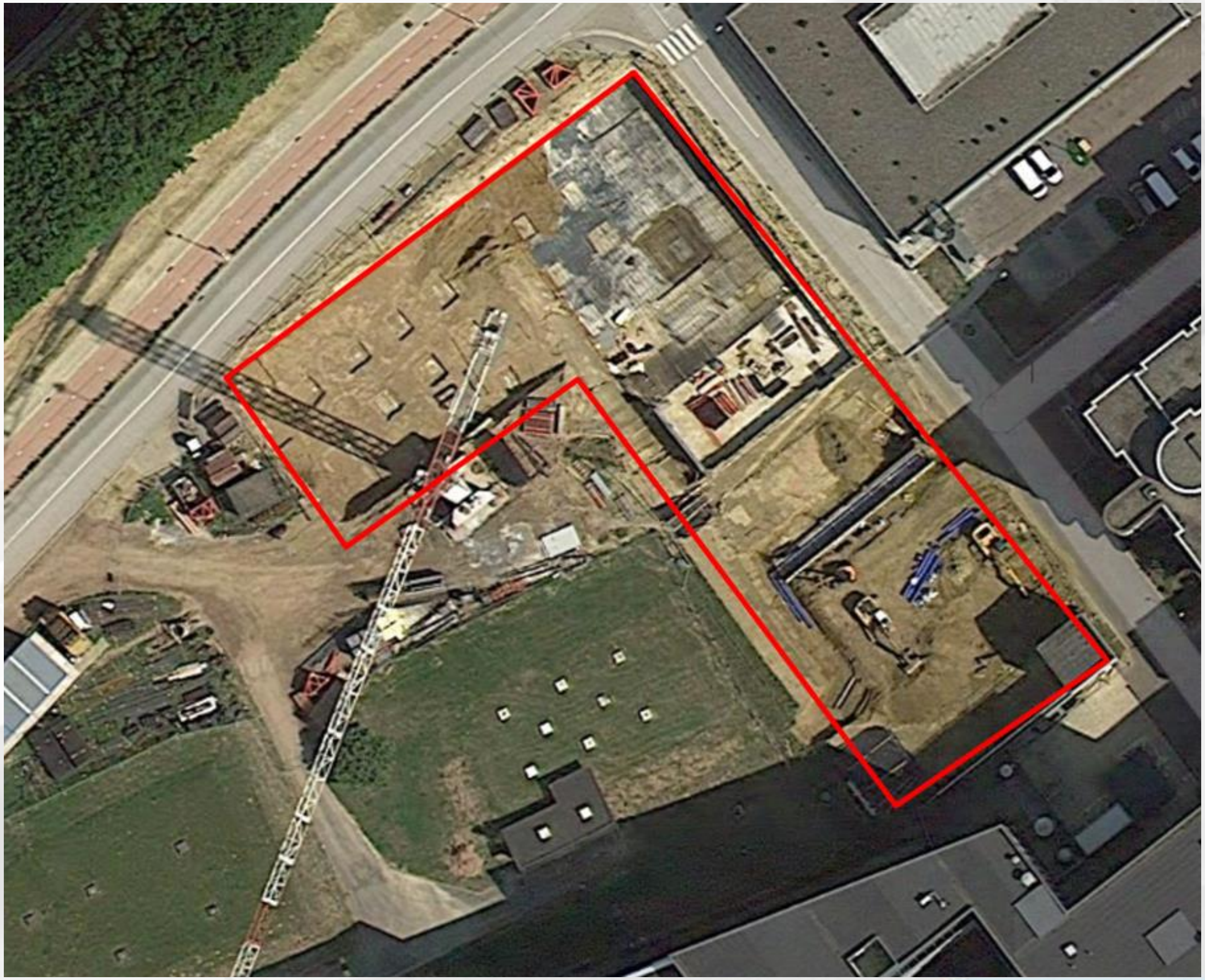
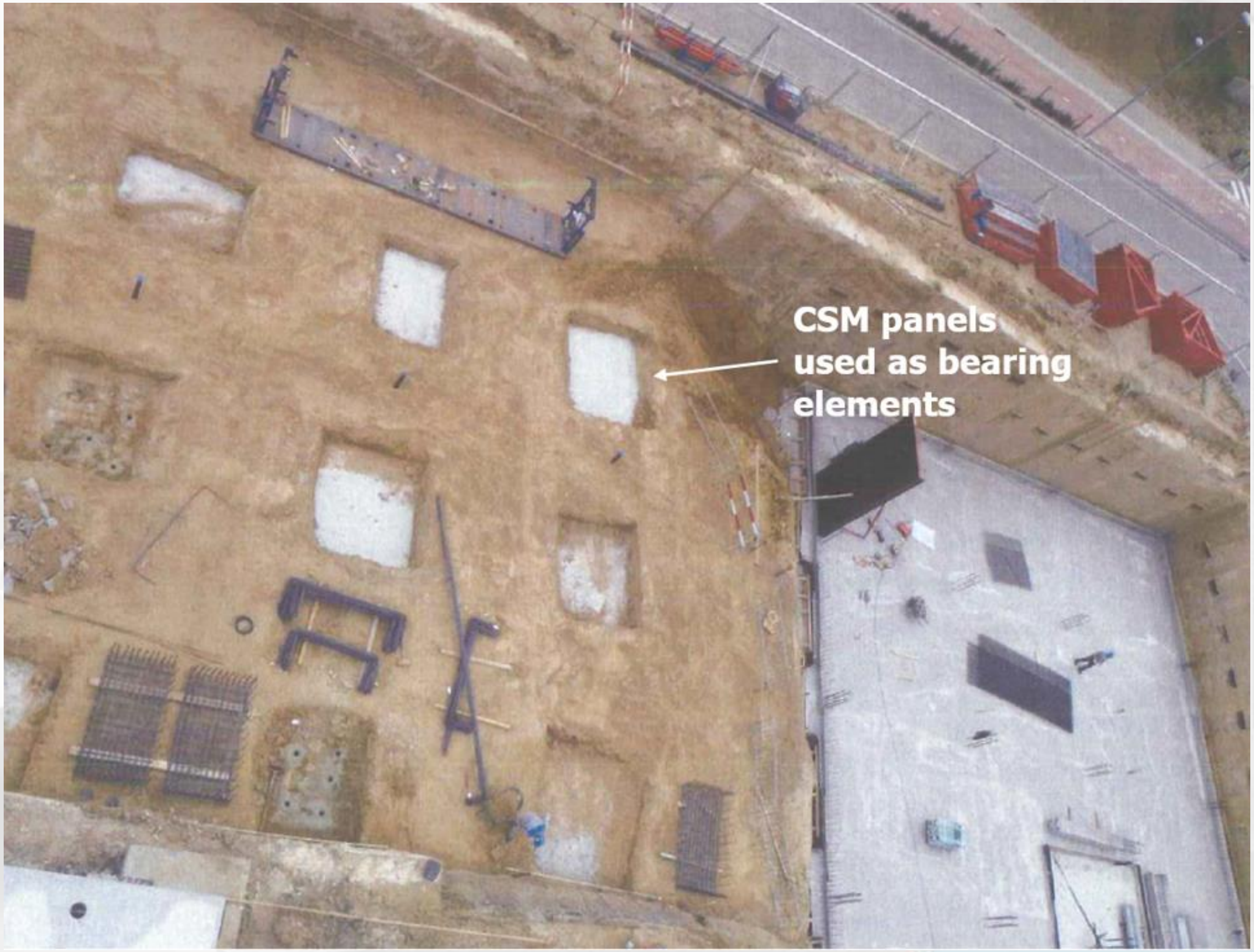


Aerial view during the execution of the works by Soetaert nv (Google view – July 2013)

4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements



4. Hybrid concept without load transfer platform

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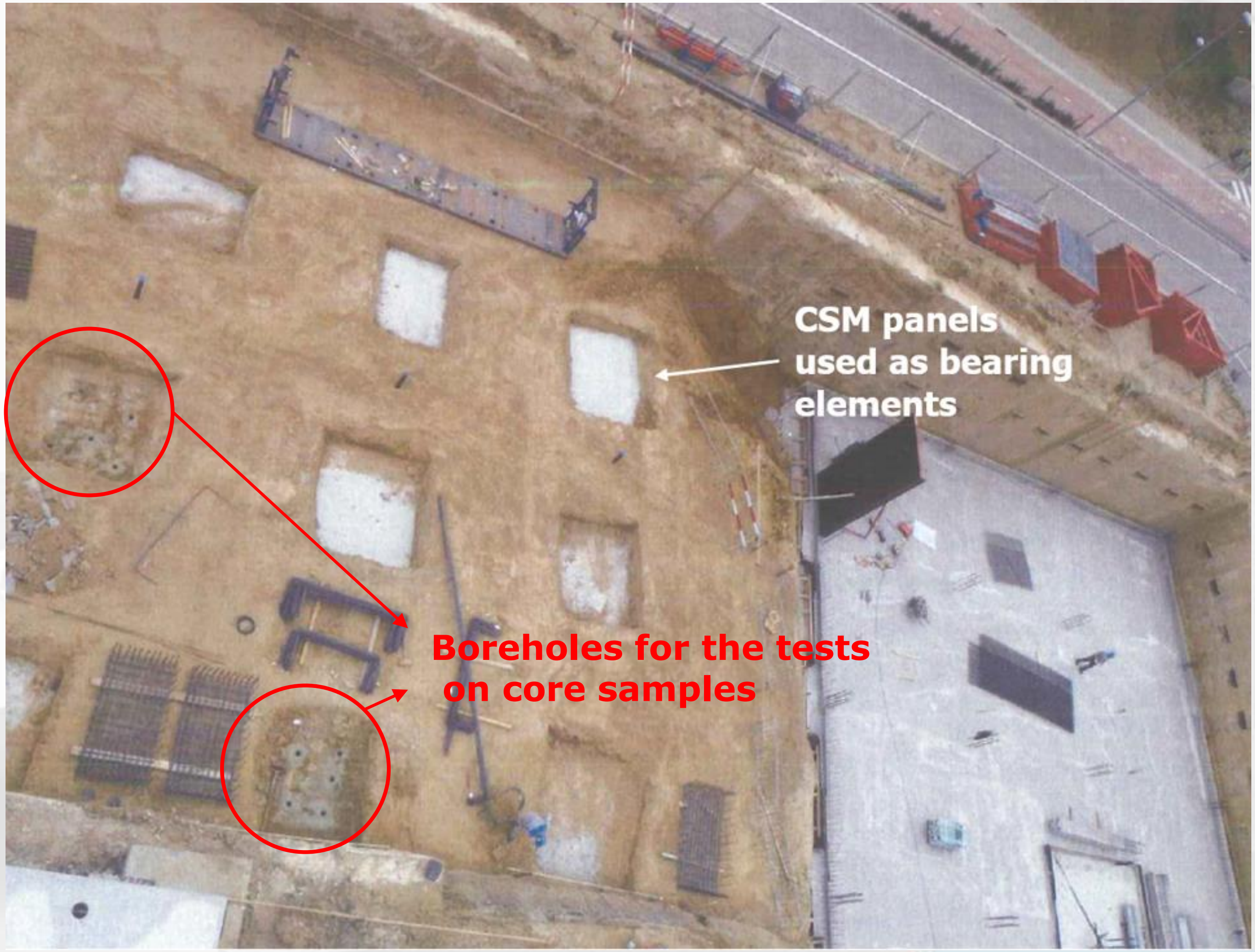

4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Design of the CSM-panels as bearing elements

- **No rigid connection with the building structure**
- **Design for compression → no reinforcement**
- **f_{cd} > q (f_{cd} → Handbook soilmix-wanden and tests on core samples)**

4. Hybrid concept without load transfer platform

Soil mix elements used as b

Design of the CSM-panels as be

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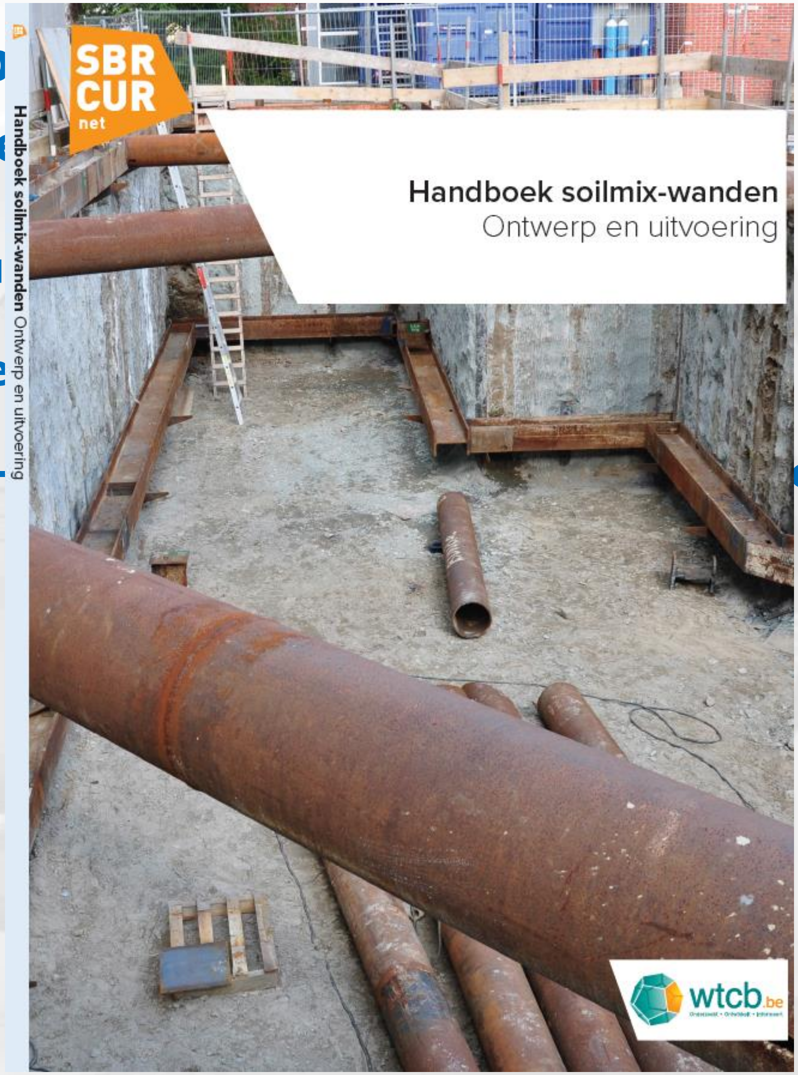

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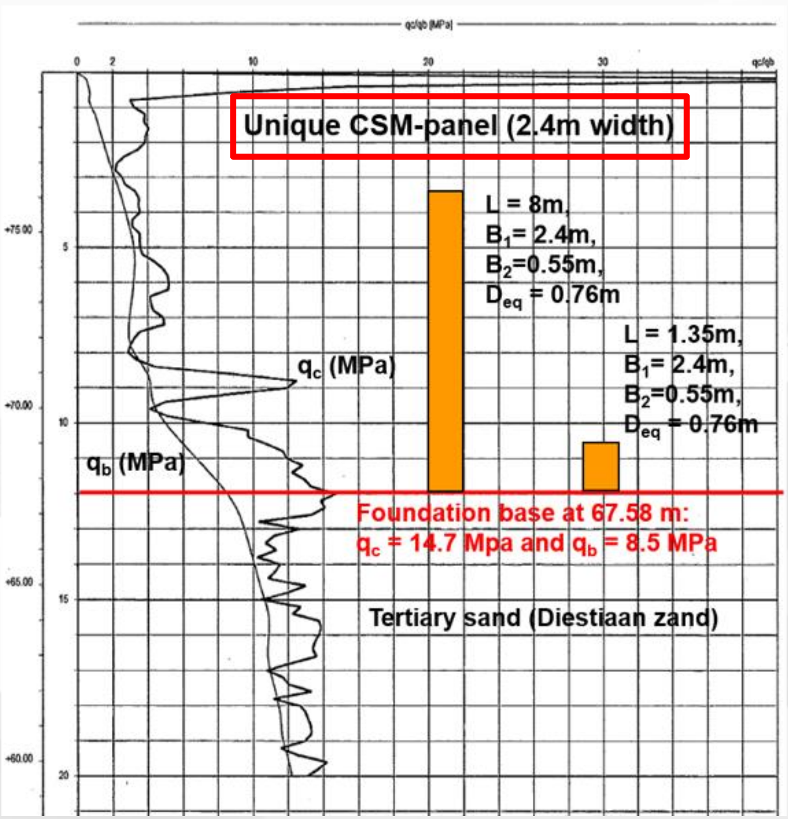
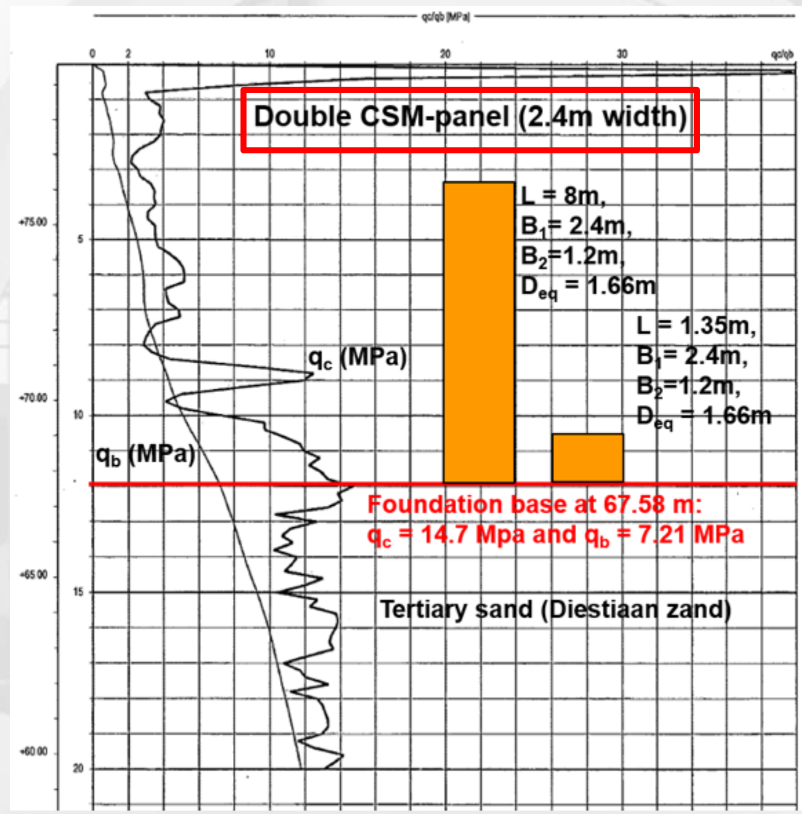
- **f_{cd} > q (f_{cd} → Handbook soilmix-wanden and tests on core samples)**
- **Full vertical coring of a bearing element for QA/QC**
- **Geotechnical design → only base resistance (De Beer method)**
  → no shaft resistance

4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Design of the CSM-panels as bearing elements



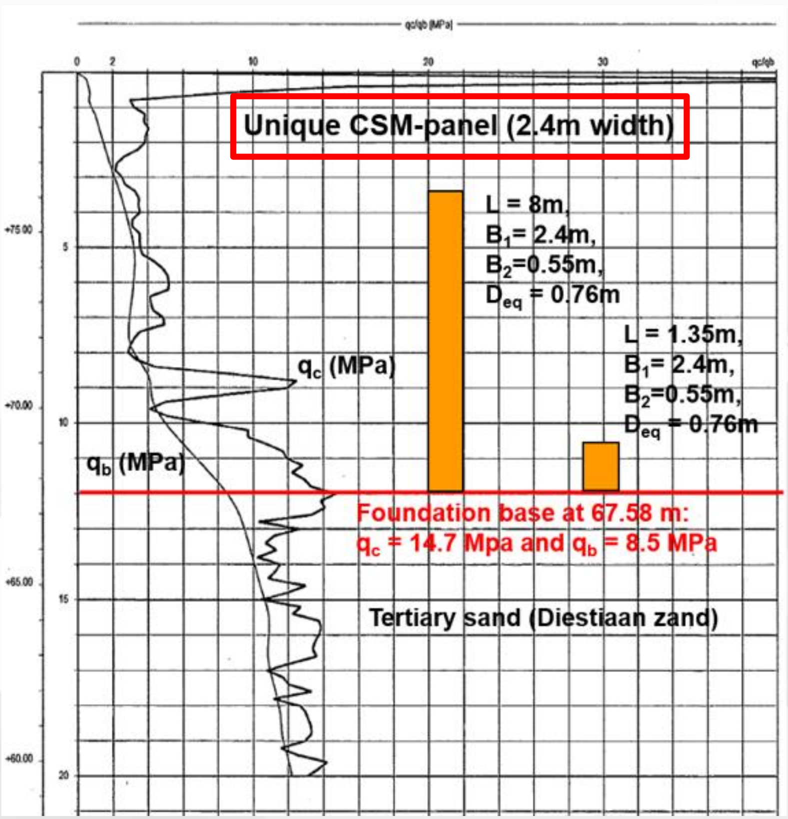


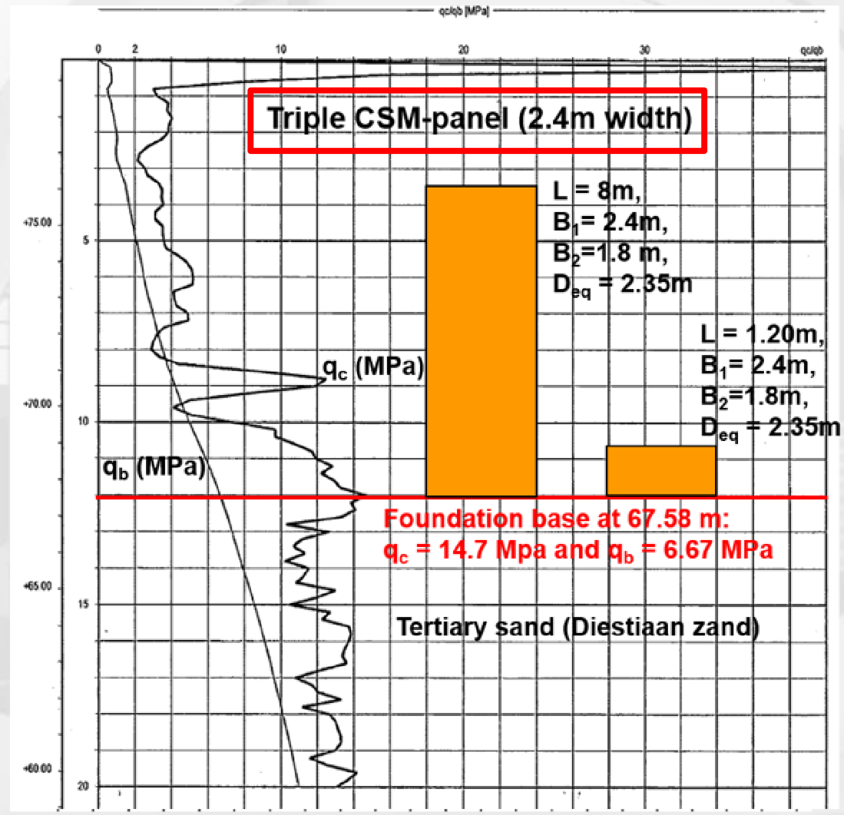
High dimensions of the base area → important base resistance!

4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Design of the CSM-panels as bearing elements





High dimensions of the base area → important base resistance!

4. Hybrid concept without load transfer platform

Soil mix elements used as bearing elements

Design of the CSM-panels as bearing elements – discussion points

- **In this concept: building slabs directly installed on the CSM-panels**
  - **What is the effect of the absence of the LTP?**
  - **What is the role of the soil in the concept?**
- **Quality of the soil mix material on the first meter**
- **Durability of the soil mix element (on the first meter)**
  - **Effect of frost/thaw or wet/dry cycli? Carbonation?**

4. Hybrid concept without load transfer platform

Soil mix elements used as b

Design of the CSM-panels as be

– discussion points

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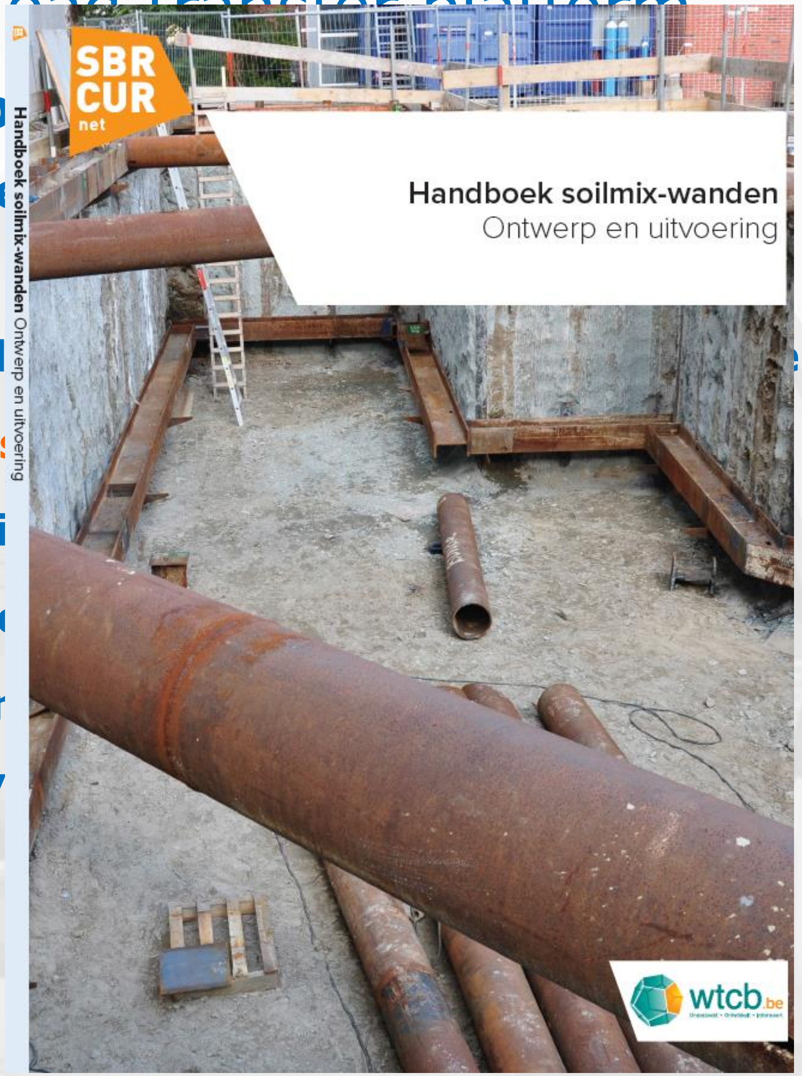
- **Durability of the soil mix elemen**
  - **Effect of frost/thaw or wet/**



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4. Hybrid concept without load transfer platform

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  - **Effect of frost/thaw or wet/dry cycli? Carbonation?**
- **Geotechnical design of the bearing capacity**
  - **Computed as a pile or as a high dimension caisson?**

    → Respect of the element dimensions!
  - **No shaft friction? → Monitoring perspectives!**

4. Hybrid concept without l

Soil mix elements used as b

Design of the CSM-panels as be

– discussion points

- ❖ **In this concept: building slabs d** s
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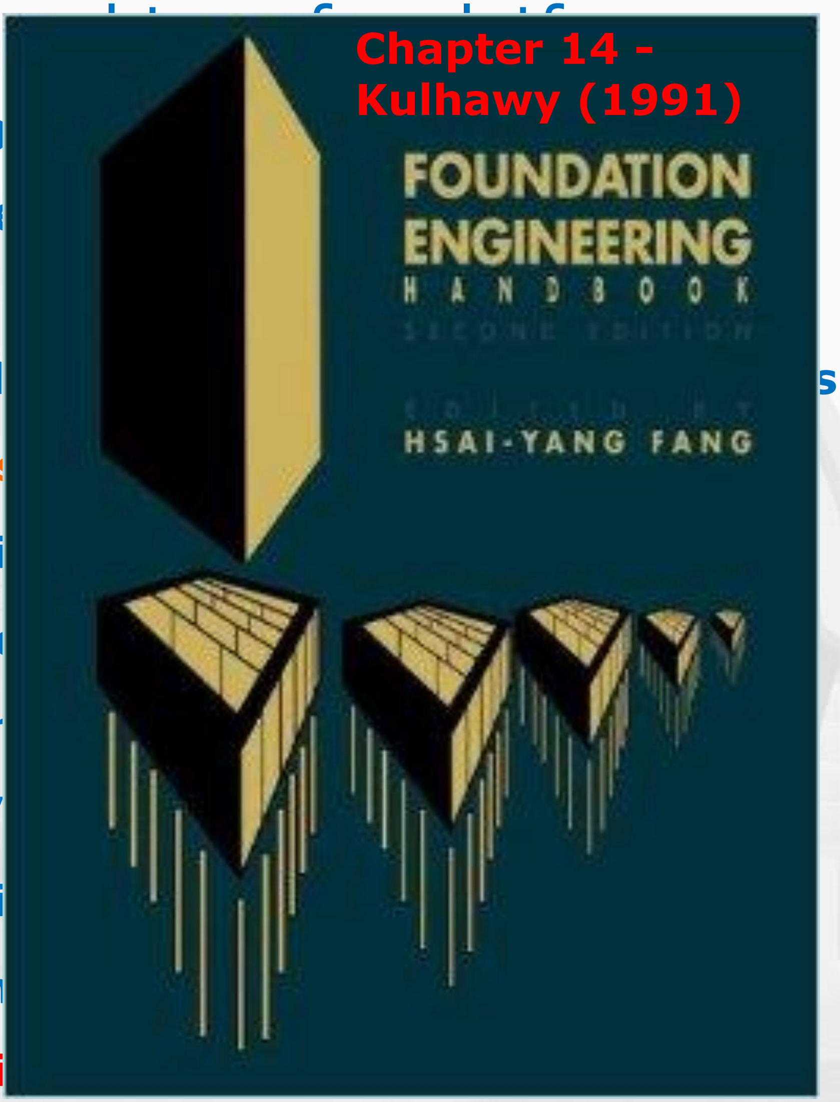

5. Conclusions and perspectives

Ground improvement vs. pile foundations?

To avoid an unfair competition and unbalanced requirements

- **Suited terminology and definition of the foundation concept**

  Shallow, pile, pile raft foundations and ground improvement

Rigid inclusions with a load transfer platform

- **Design approaches in line with the Eurocodes**


ASIRI NATIONAL PROJECT
Recommendations for the design, construction and control of rigid inclusion ground improvements
Summary
Close
IREX
Presses des Ponts


Bouwen met kennis
CUR
BOUW & INFRA
C.R.O.W
Delft Cluster
226
Ontwerprichtlijn paalmatrassystemen

TC 211 — SIMSG ISSMGE — BGGG - GBMS — ETC 3

5. Conclusions and perspectives

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Hybrid concepts without load transfer platform

- **Trend = use of soil mix elements as alternative to piles**
- **Requirements in line with the Eurocodes for temporary and permanent soil mix elements with a bearing function**

5. Conclusions and perspe

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Hybrid concepts without load t

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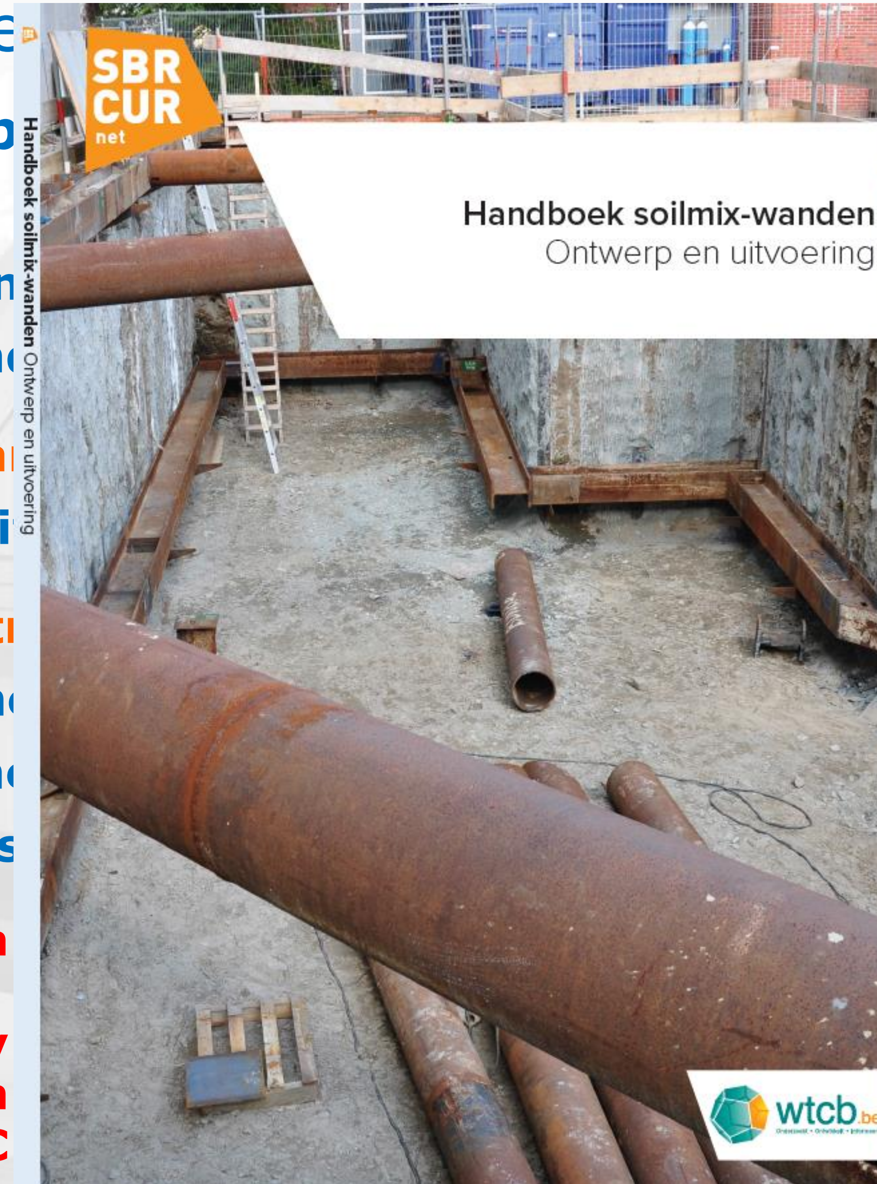
- Requirements in line with th
  permanent soil mix elements

Bearing function
GEO and STR designs
Durability
Corrosion
QA/QC



5. Conclusions and perspectives

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Hybrid concepts without load transfer platform

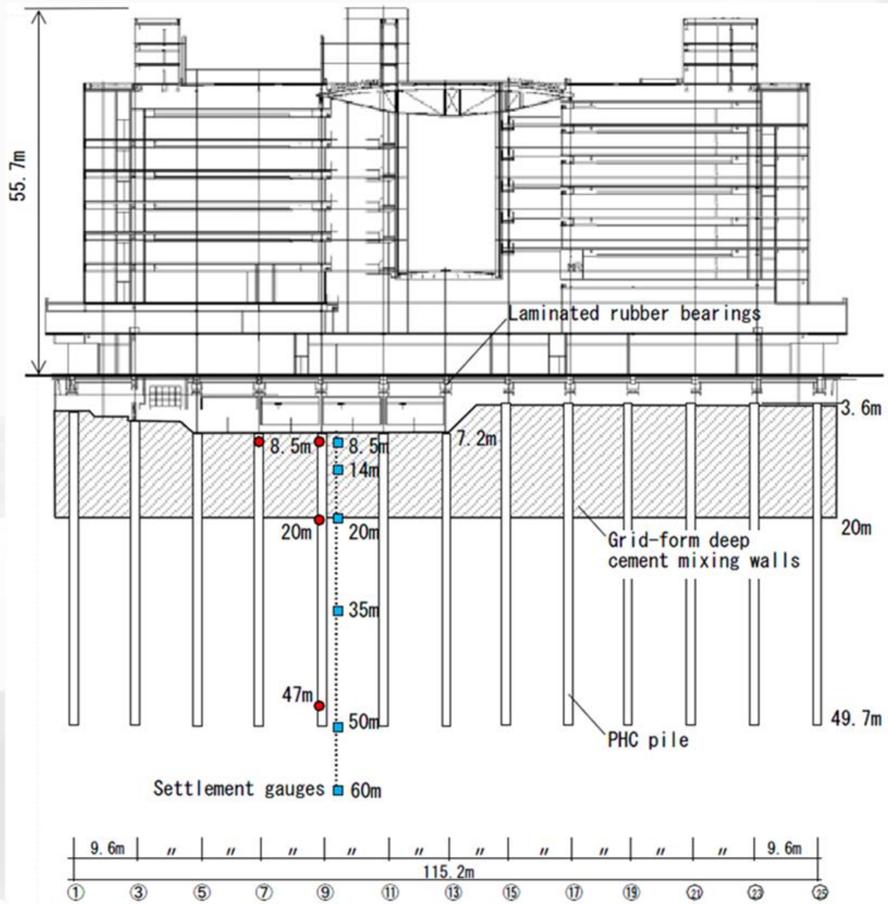
- **Trend = use of soil mix elements as alternative to piles**
- **Requirements in line with the Eurocodes for temporary and permanent soil mix elements with a bearing function**
- **Discussion points (absence of LTP?, role of the soil?...)**
  → Research perspectives and in-situ monitoring

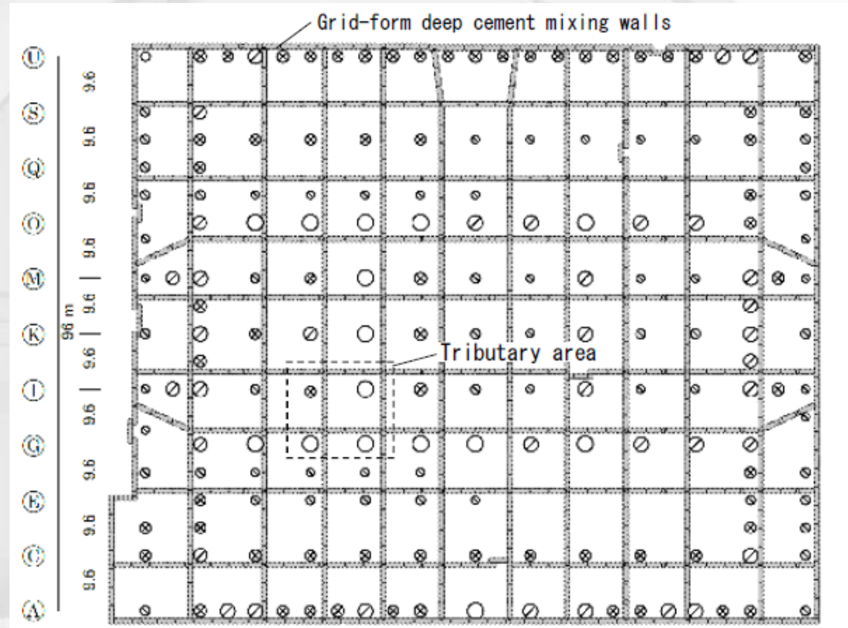
Recent trend: not in competition but in combination !

5. Conclusions and perspectives

Ground improvement AND pile foundations

Optimized design approach – twelve-story building in Tokyo





Soil mix walls for liquefaction mitigation and cost reduction:
70 % of the load taken by the piles
14 % by the soil mix walls
15 % by the soil

Yamashita et al. (ICSMGE 2013)

2006

WeeHawken residential resort
in New Jersey / USA

Ensemble résidentiel de WeeHawken
New Jersey / Etats-Unis

APAGEO

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Researches • Develops • Informs

Thank you for your attention