2SGT2019

2nd SEMINAR
ON TRANSPORTATION
GEOTECHNICS

SOIL IMPROVEMENT CHALLENGES ON ALLUVIAL ZONES

28-29 January 2019
Vila Franca de Xira, Portugal

Presentations e-Book
Volume 2

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Volume 2

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SUPPORT

CONTENTS

MODULE II - Latest Soil Improvement Techniques

CONTENTS

MODULE II - Latest Soil Improvement Techniques (cont.)

MODULE II

Latest Soil Improvement Techniques

Soil improvement by jet grouting for the construction of the Access to the Barcelona Airport
Application of the recent technologies

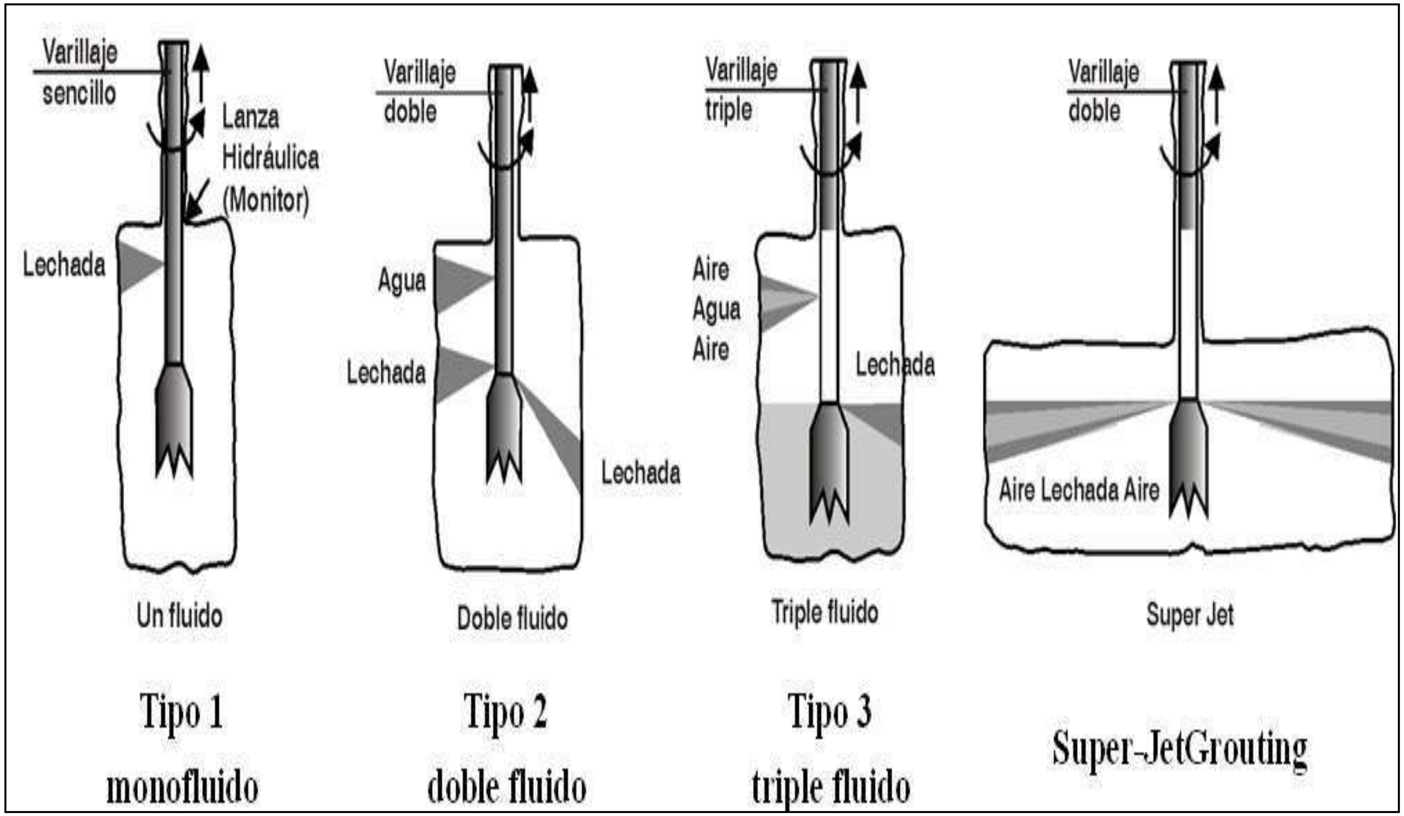
Goran Vukotić

Keller

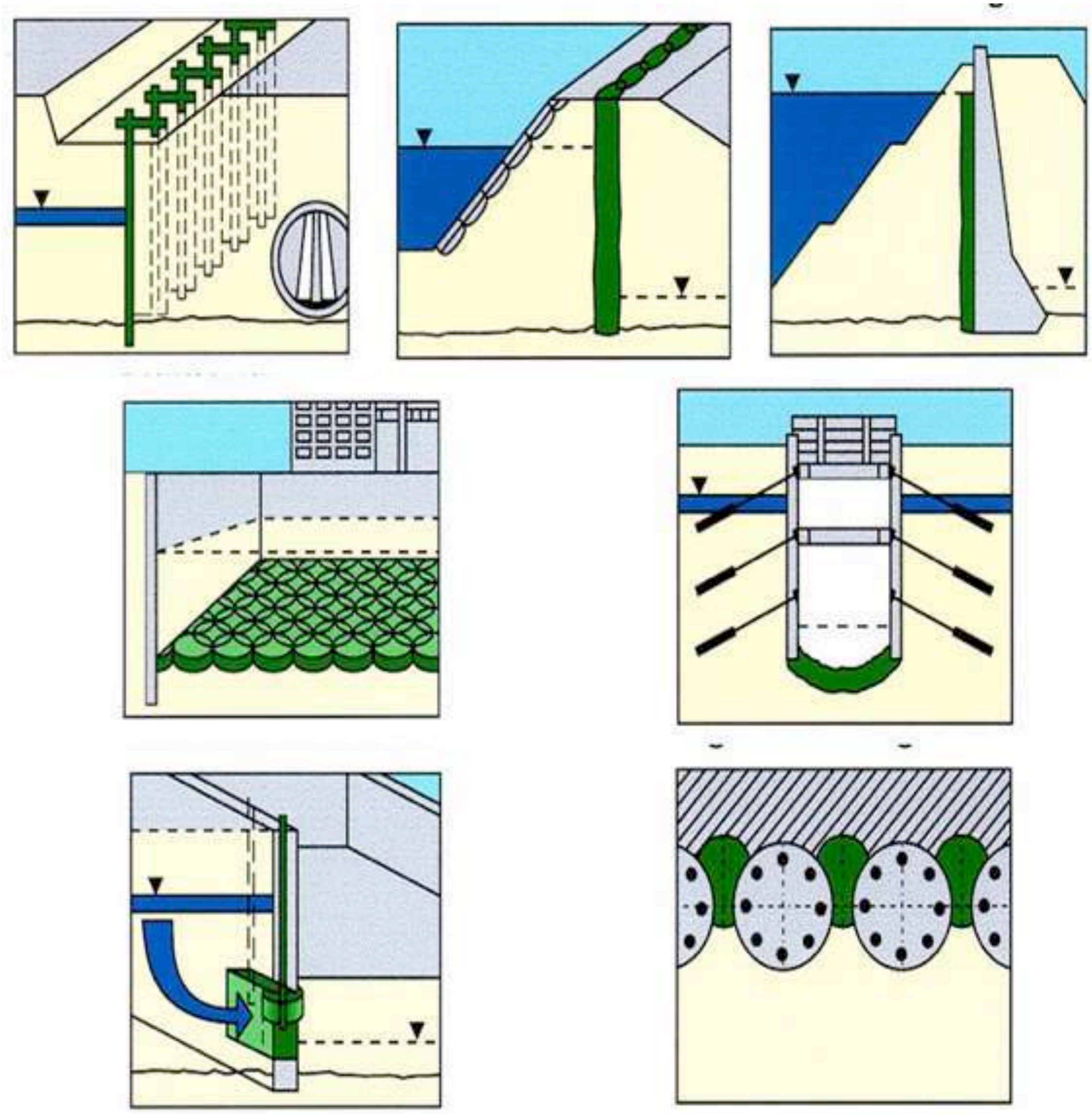
JET GROUTING:

- Introduced to the field of geotechnical engineering more than 40 years ago.
- It primarily acts in the ground either as a mean of stabilization or as a sealing structure.
- The eroded soil is rearranged and mixed with the cement suspension.
- The result is a structured element or column, which has improved mechanical characteristics compared with the original soil.

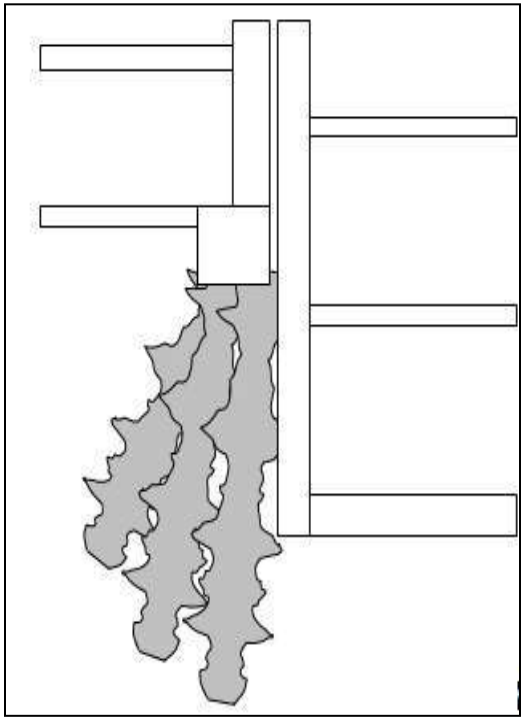
- JET GROUTING:
- Different types of jet grouting:

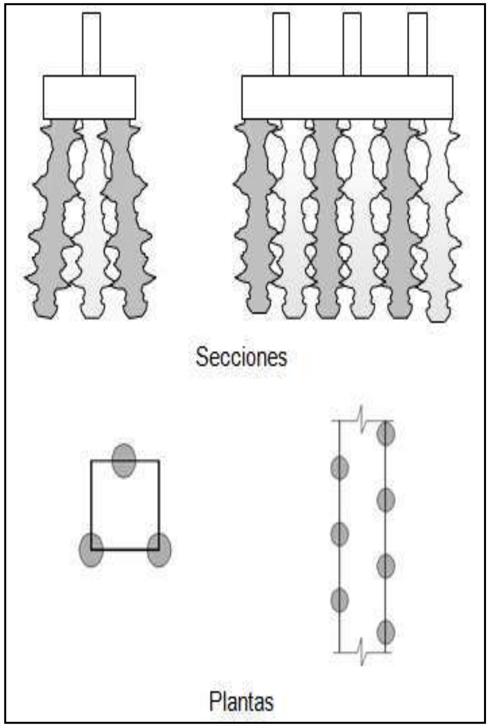


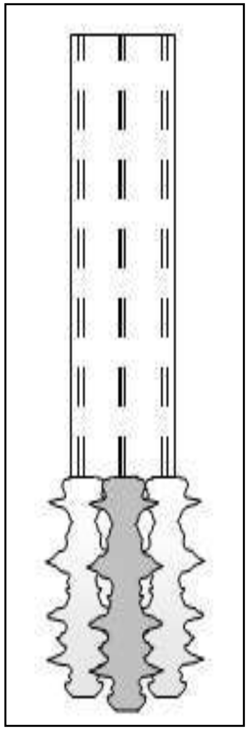
- JET GROUTING:
- Different types of applications:
  - Sealing structures



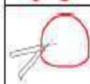
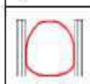
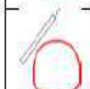
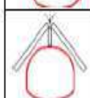
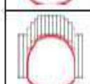
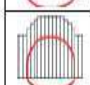
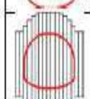
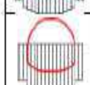
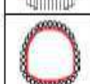
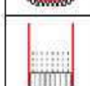
- JET GROUTING:
- Different types of applications:
  - Stabilization and soil improvement
    - Escavation pits
    - New foundation
    - Underpinning







- JET GROUTING:
- Different types of applications:
  - Tunneling

SIGNO	DESCRIPCIÓN
	Jet-grouting horizontal en bóveda (paraguas)
	Jet-grouting horizontal en solera.
	Jet-grouting horizontal en bóveda para emboquilles.
	Jet-grouting para la estabilización de los hastiales desde la plataforma de excavación.
	Jet-grouting para la estabilización de los hastiales desde fuera de la plataforma de excavación.
	Jet-grouting para la estabilización de los hastiales desde fuera de la plataforma de excavación.
	Barreras jet-grouting para intercepción de subsidencias
	Inyecciones jet-grouting en forma de "tienda de campaña", "haima" o "montera"
	Estabilización bóveda mediante inyección de columnas secantes jet-grouting adaptadas a la directriz transversal del túnel.
	Estabilización bóveda mediante inyección de columnas secantes jet-grouting que dan lugar a un macizo (sin cubrir solera)
	Estabilización bóveda mediante inyección de columnas secantes jet-grouting que dan lugar a un macizo (cubriendo solera)
	Estabilización solera mediante inyección de columnas secantes jet-grouting que dan lugar a un macizo (sin cubrir bóveda)
	Jet-grouting horizontal en 360°.
	Tratamiento jet-grouting para tapón de fondo en excavaciones entre pantallas.

- Soil improvement by jet grouting for the construction of the Access to the Barcelona Airport
  Application of the recent technologies

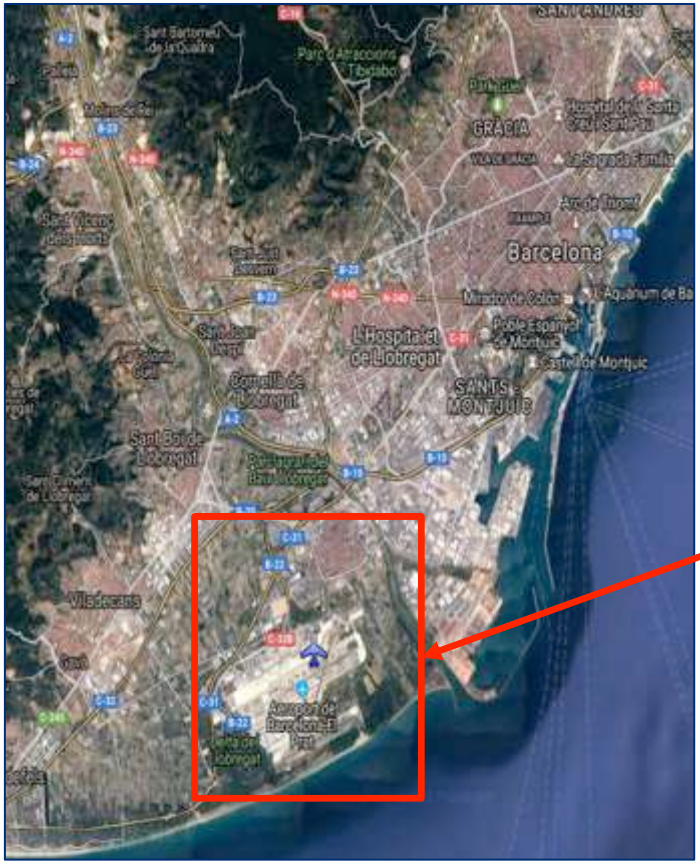
KELLER

- With its famous football team and history as an Olympic city, Barcelona is no stranger to breaking records.

- Jet grouting project at Barcelona airport is just one more on the list of breaking records for this unique centre of culture and sport.

- Started in May 2016 and was completed in April 2018, Keller drilled 279.000 m, jetted 89.000 m and deployed four rigs on double shifts, six days per week.
- This jet grouting project is a record in Spain and it is one of the largest ever performed in Europe.

LOCATION



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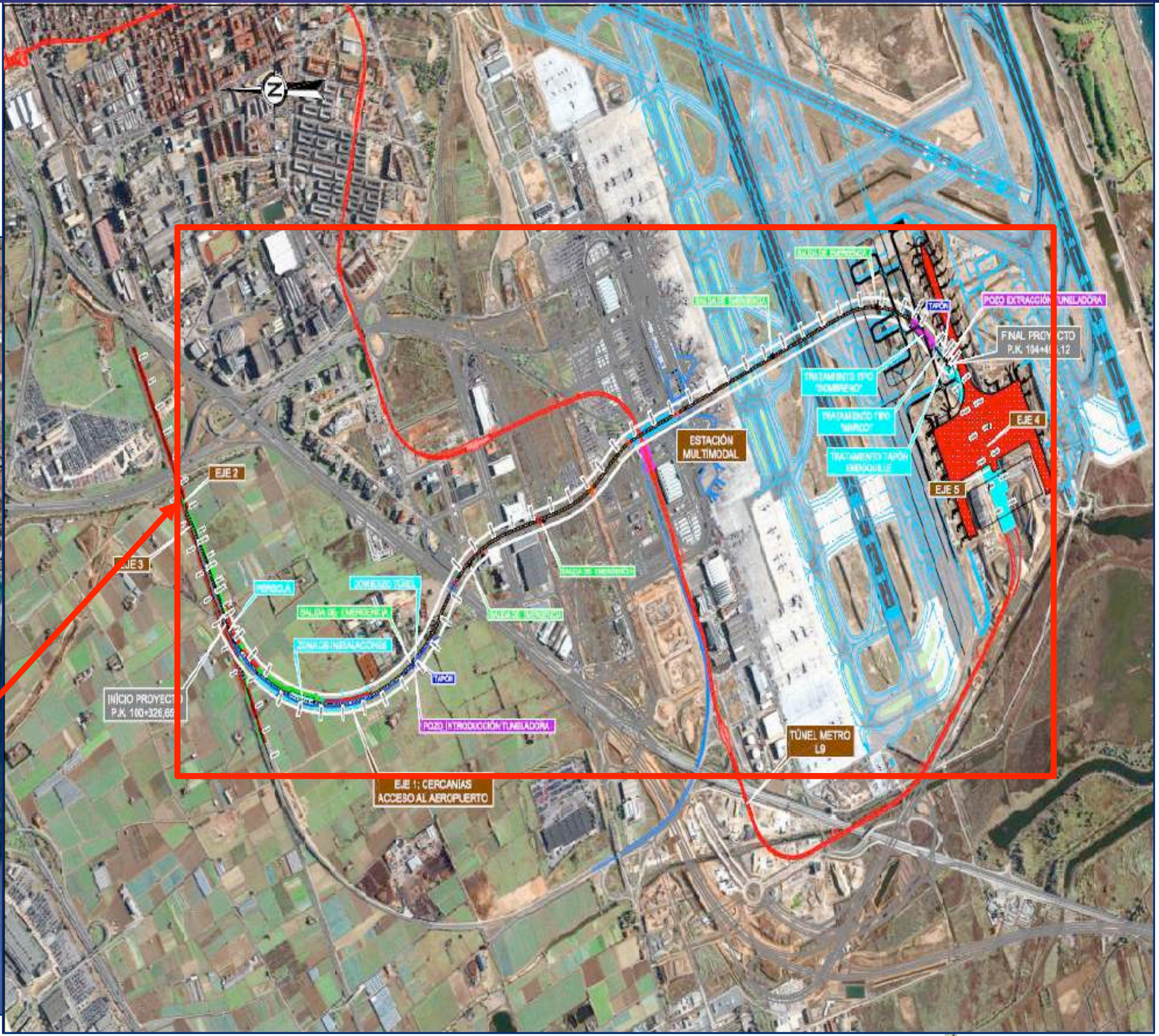
LOCATION

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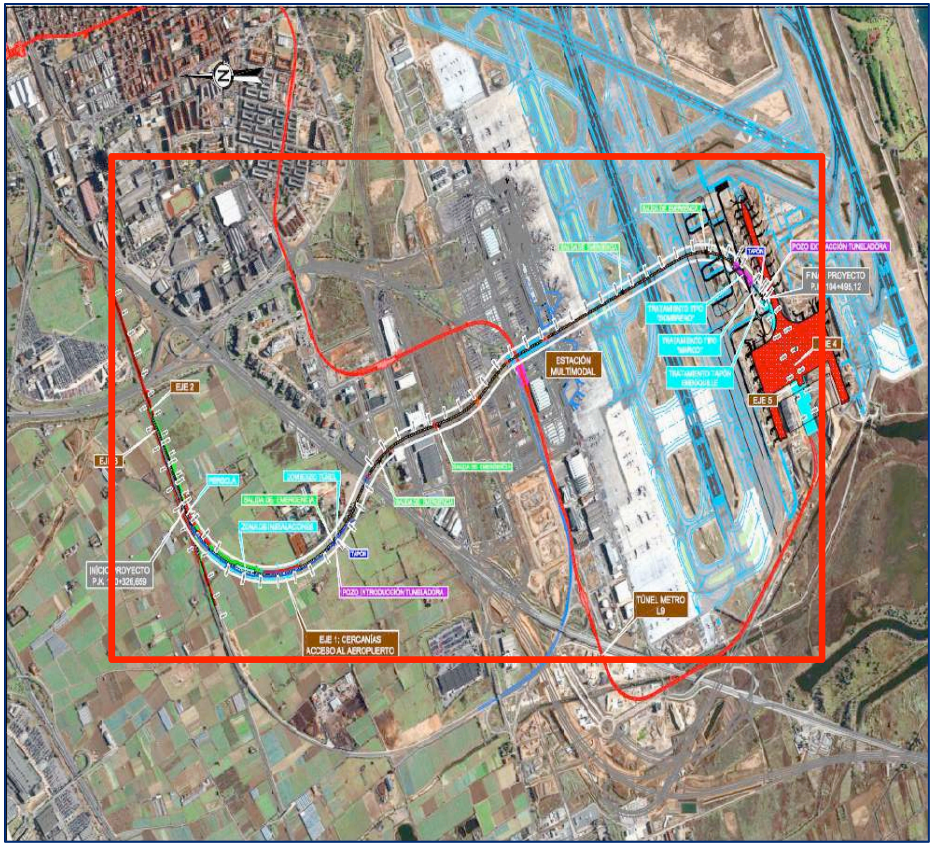
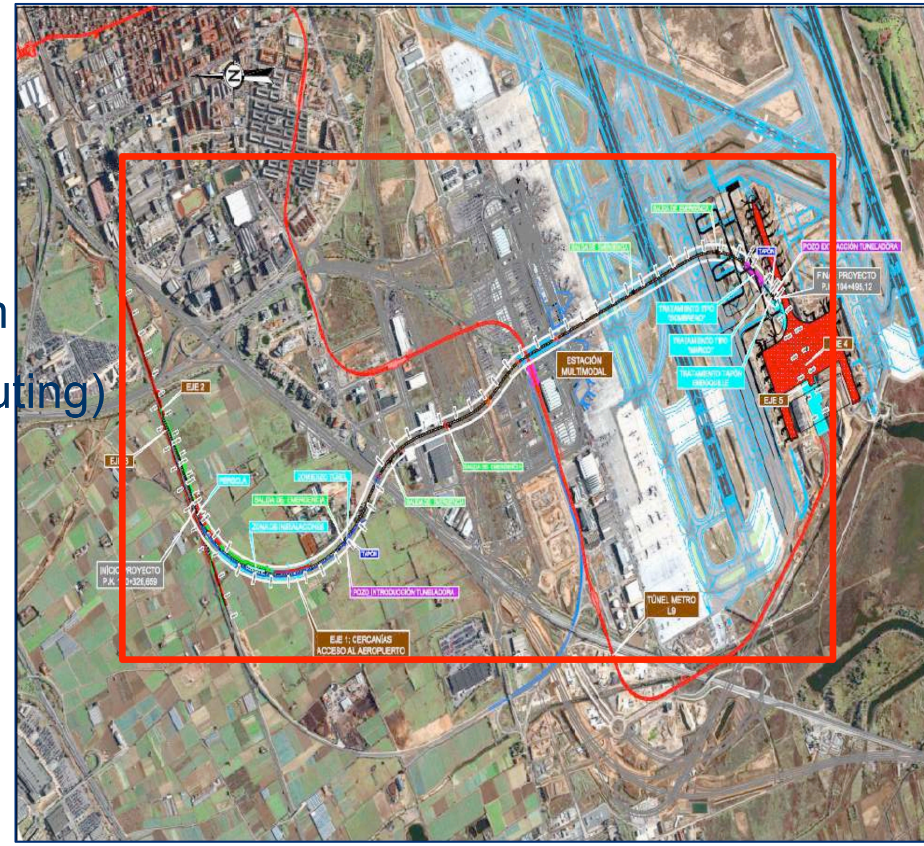
GENERAL PROJECT DATA

- Spanish Ministry for Public Works
- Railway connection to the Airport
- 4,5 km tunnel (2,8 km TBM)
- New Intermodal Station
- MC: JV Sacyr-Ferrovial-Copcisa
- 40 months execution period



GENERAL PROJECT DATA

- Spanish Ministry for Public Works
- Railway connection to the Airport
- 4,5 km tunnel (2,8 km TBM)
- Tunnel: dia. 10,8 m; max. depth 26,0 m
- 13.400 m^3 of soil improvement (jet grouting)
- 50.000 m^2 DW
- 316.000 m^3 excavation



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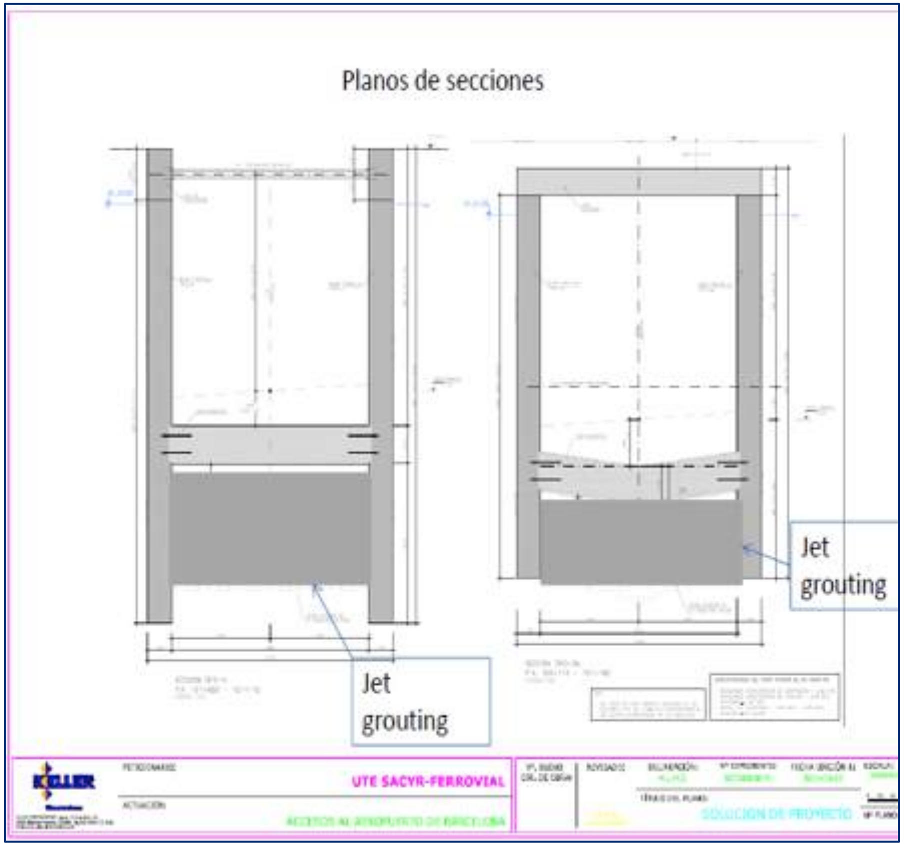
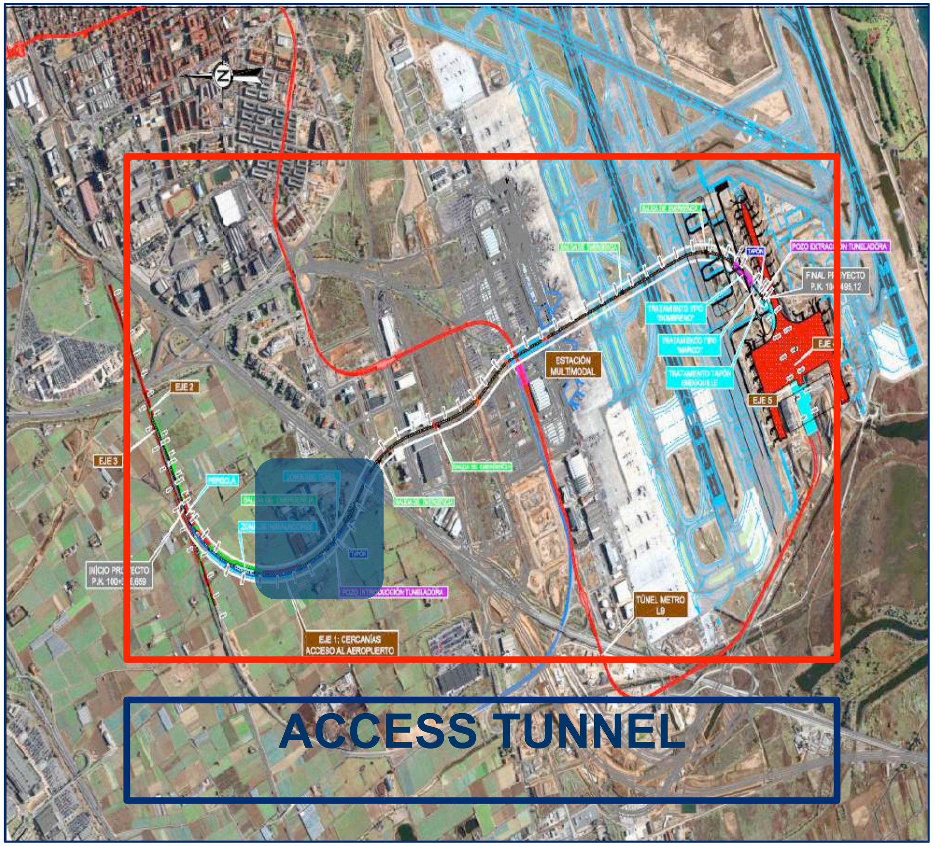
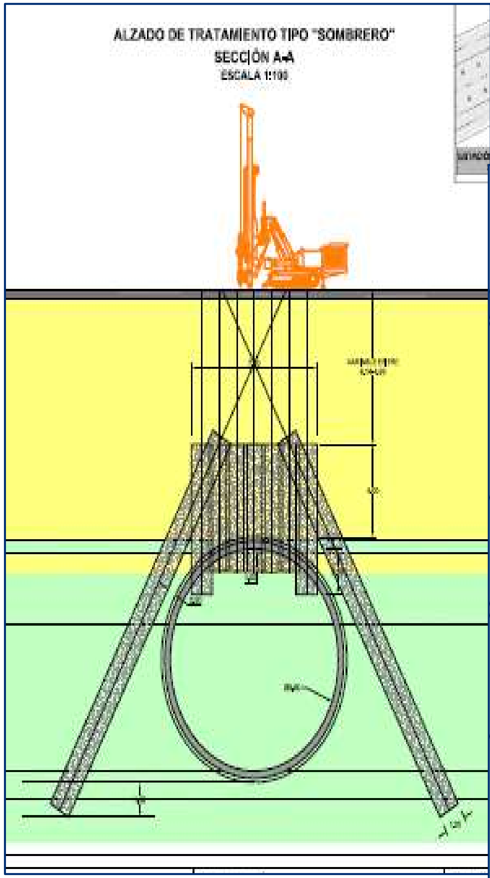
ACCESS TUNNEL

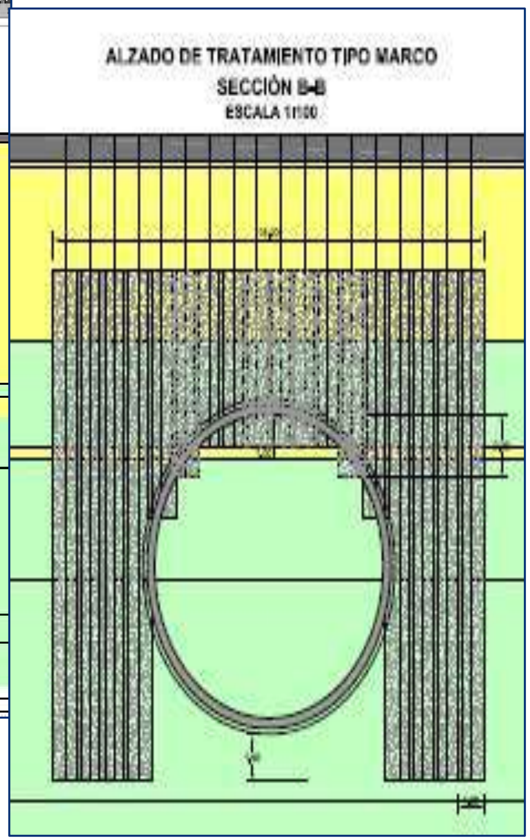




- 1,8 m dia. colum
- 19.230 m of jet grouting (2,5–5,5 m) – sealing slab and struts
- 68.400 m of drilling (15,0-35,0 m)

RUNWAY AREA

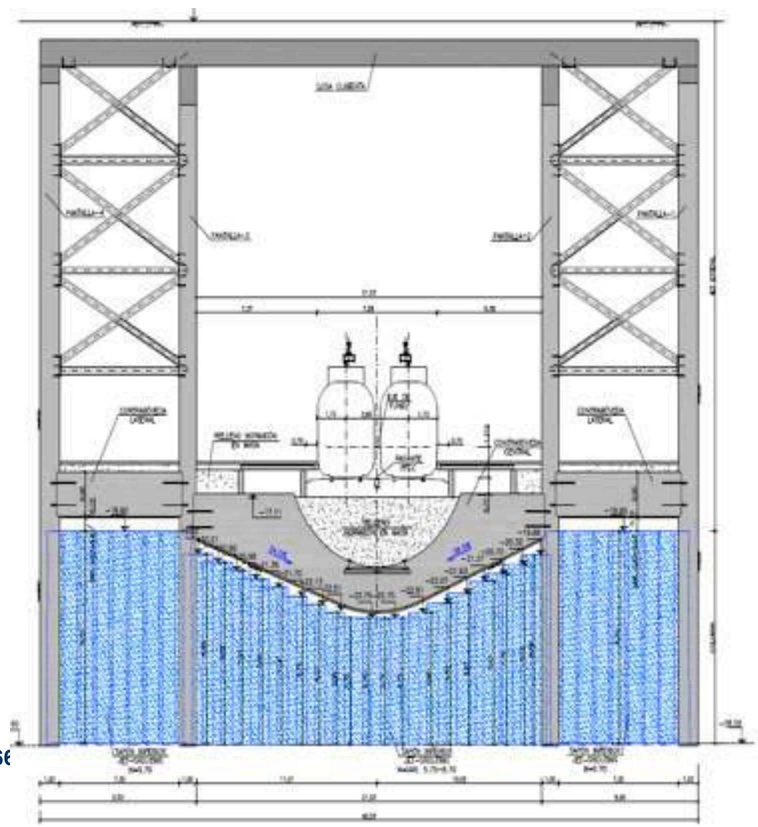


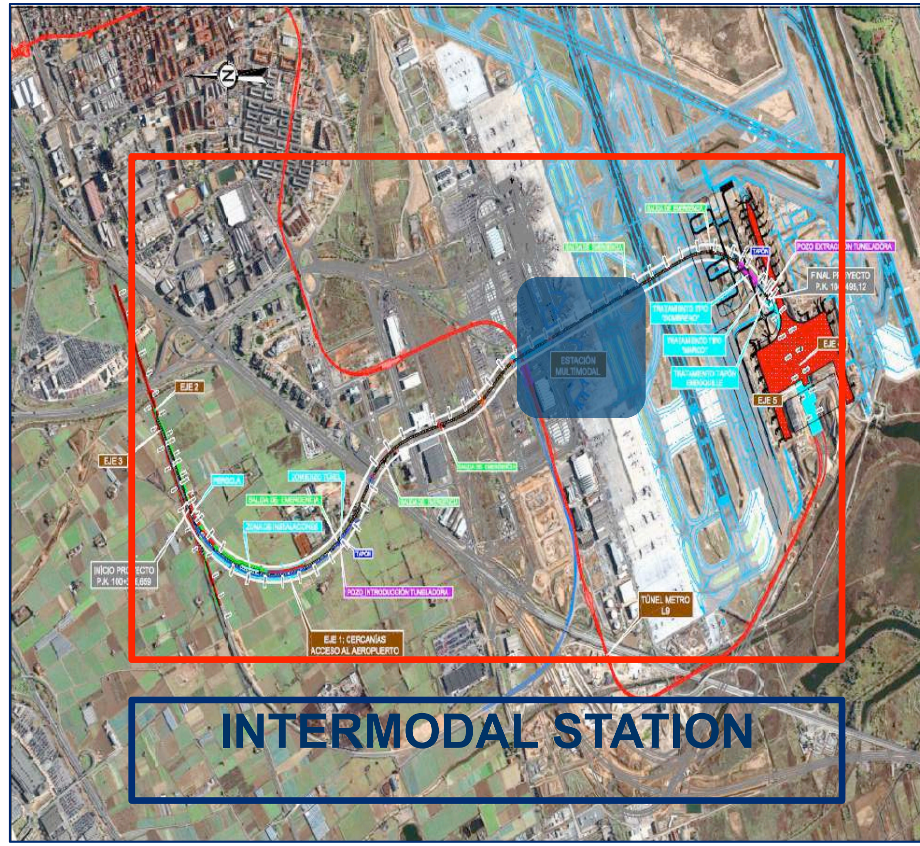


- 1,8 m dia. column
- 17.362 m of jet grouting
- 39.000 m of drilling (15.0-35.0 m)

INTERMODAL STATION

- 1,8 m dia. column
- 47.400 m of jet grouting (5,5–9,0 m)
- 186.800 m of drilling (28,0-35,0 m)





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DESIGN

- SOIL CHARACTERISTICS
- JET GROUTING DIAMETER
- COLUMN DISTRIBUTION – GRID
- STRUCTURAL ANALYSIS

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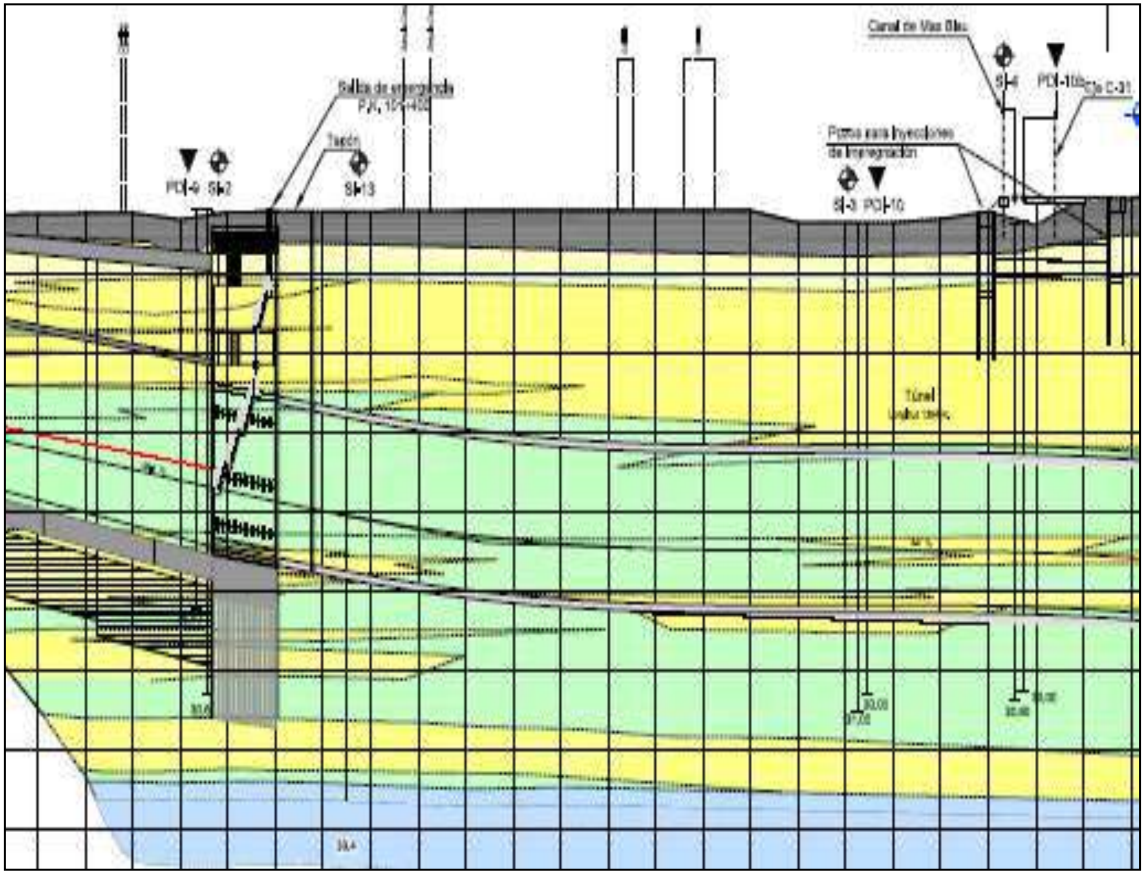
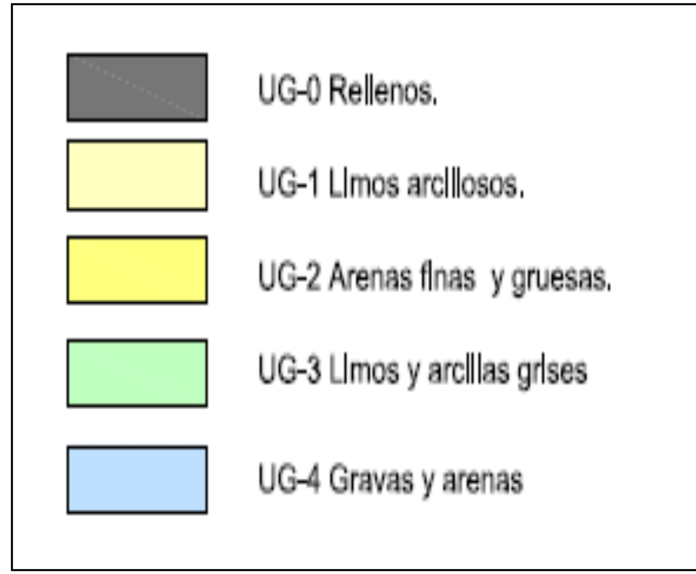
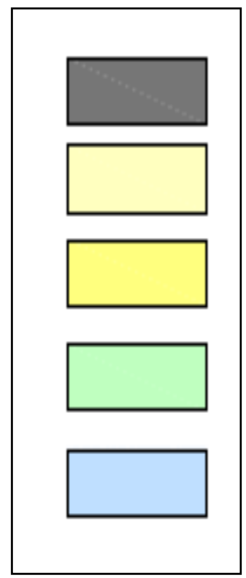
SOIL CHARACTERISTICS







- UG-0 Fill material
- UG-1 Cleyey silt
- UG-2 Fine sands
- UG-3 Silts and clay
- Gravel and sands

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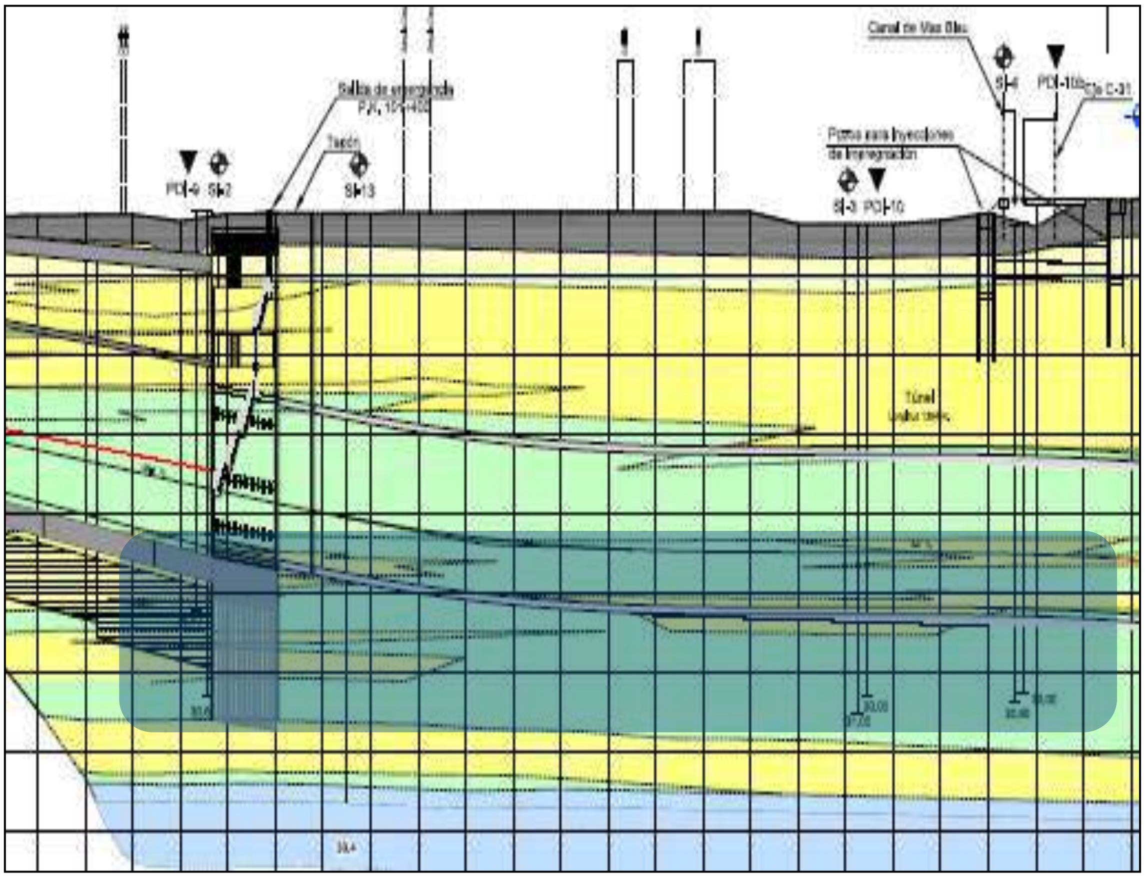
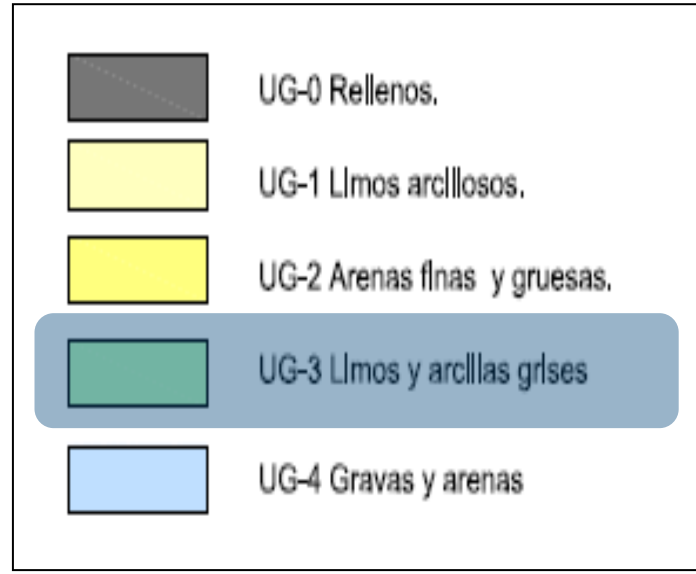
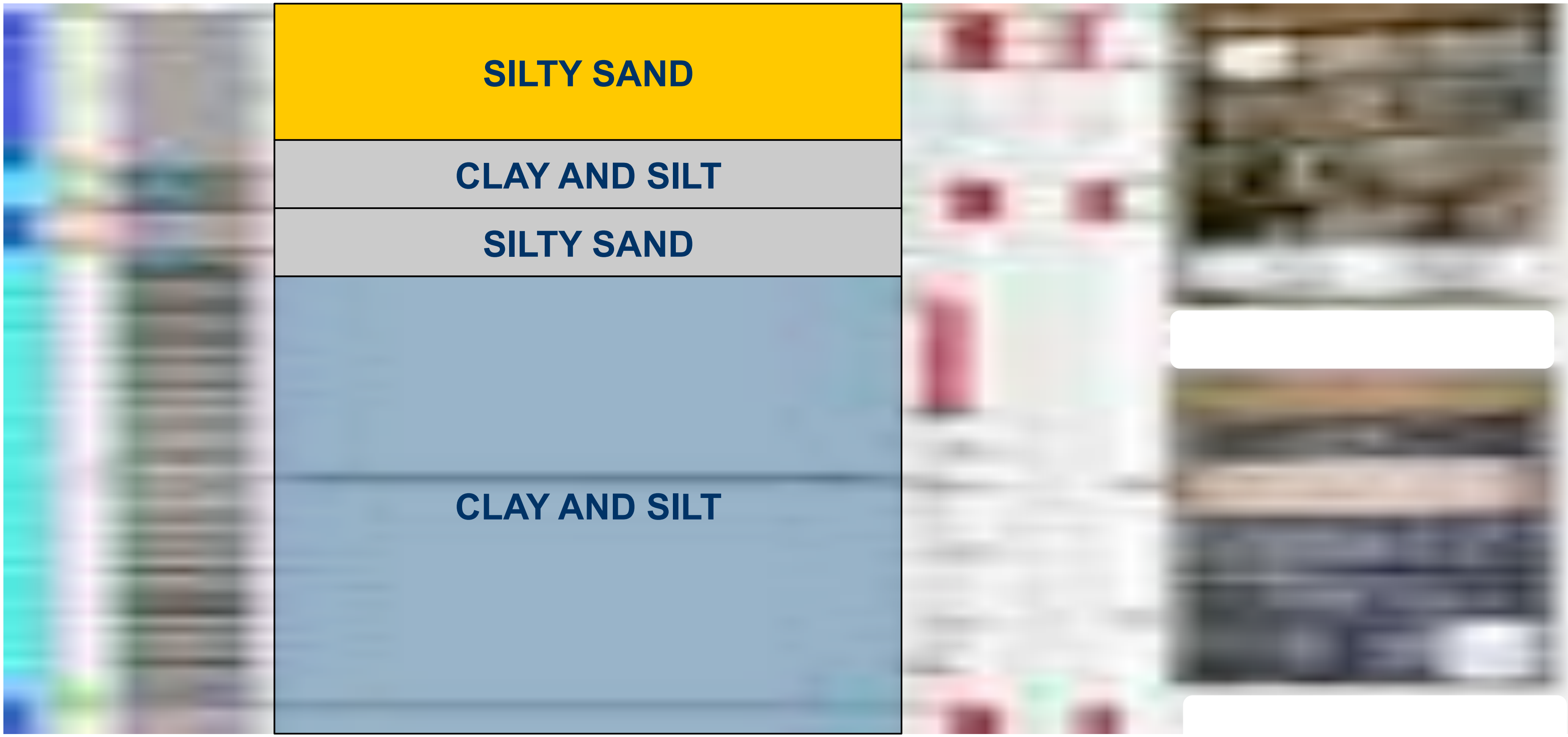
SOIL CHARACTERISTICS



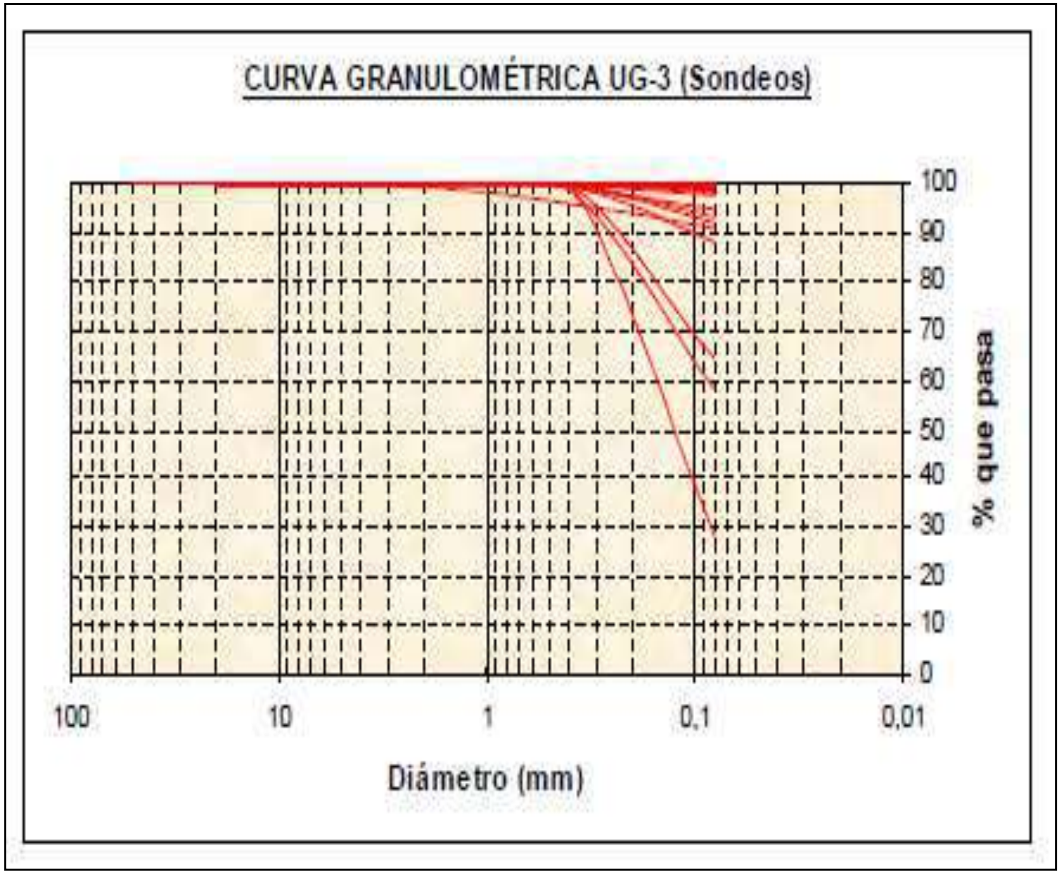


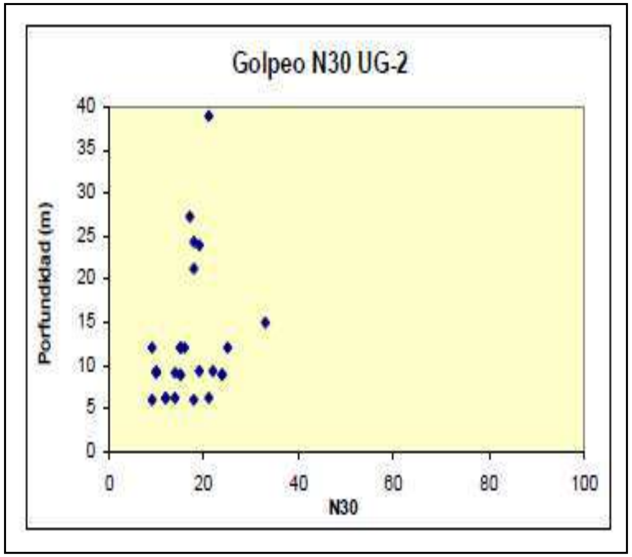
- UG-0 Fill material
- UG-1 Cleyey silt
- UG-2 Fine sands
- UG-3 Silts and clay
- Gravel and sands

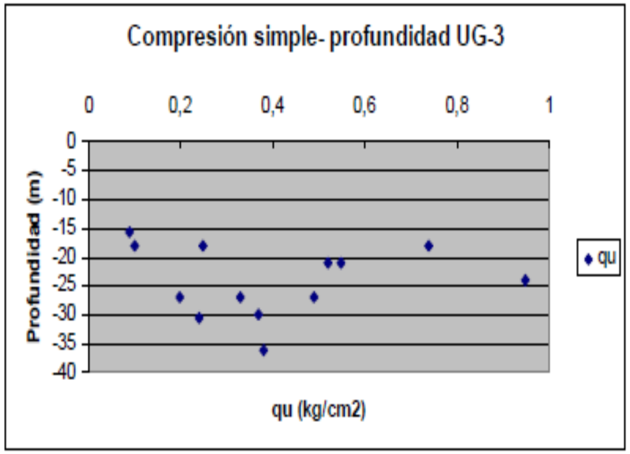
SOIL CHARACTERISTICS



SOIL CHARACTERISTICS

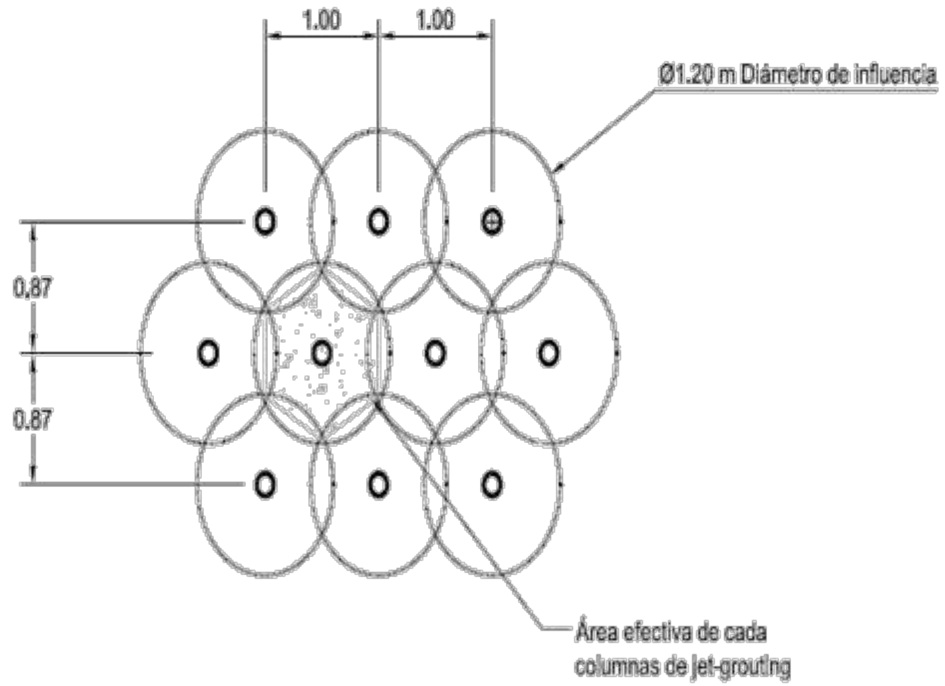






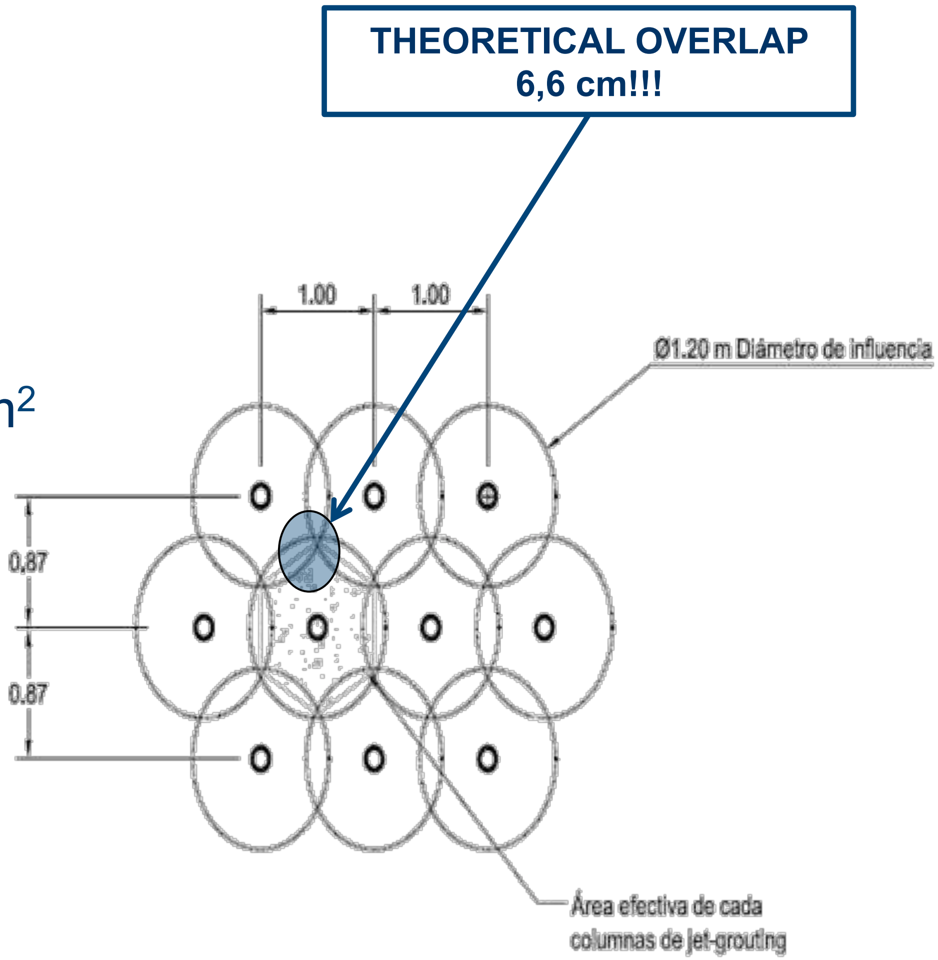
COLUMN DIAMETER

- Project initial solution:
  - dia.: 1,20 m
  - Grid: 1,0 x 1,0 m



COLUMN DIAMETER

- Project initial solution:
  - dia.: 1,20 m
  - Grid: 1,0 x 1,0 m
  - Point/Column influence: 0,87 m^2
  - Theoretical overlap: 6 cm
  - DEVIATION (VERTICALITY) NO CONSIDERED!



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COLUMN DIAMETER

THEORETICAL OVERLAP
6,6 cm!!!

- Project initial solution:
  - dia.: 1,20 m
  - Grid: 1,0 x 1,0 m
  - Point/Column influence: 0,87 m^2
  - Theoretical overlap: 6 cm
  - DEVIATION (VERTICALITY) NO CONSIDERED!
  - JGG: min. deviation 1%
  - EN12716: deviation up to 2%

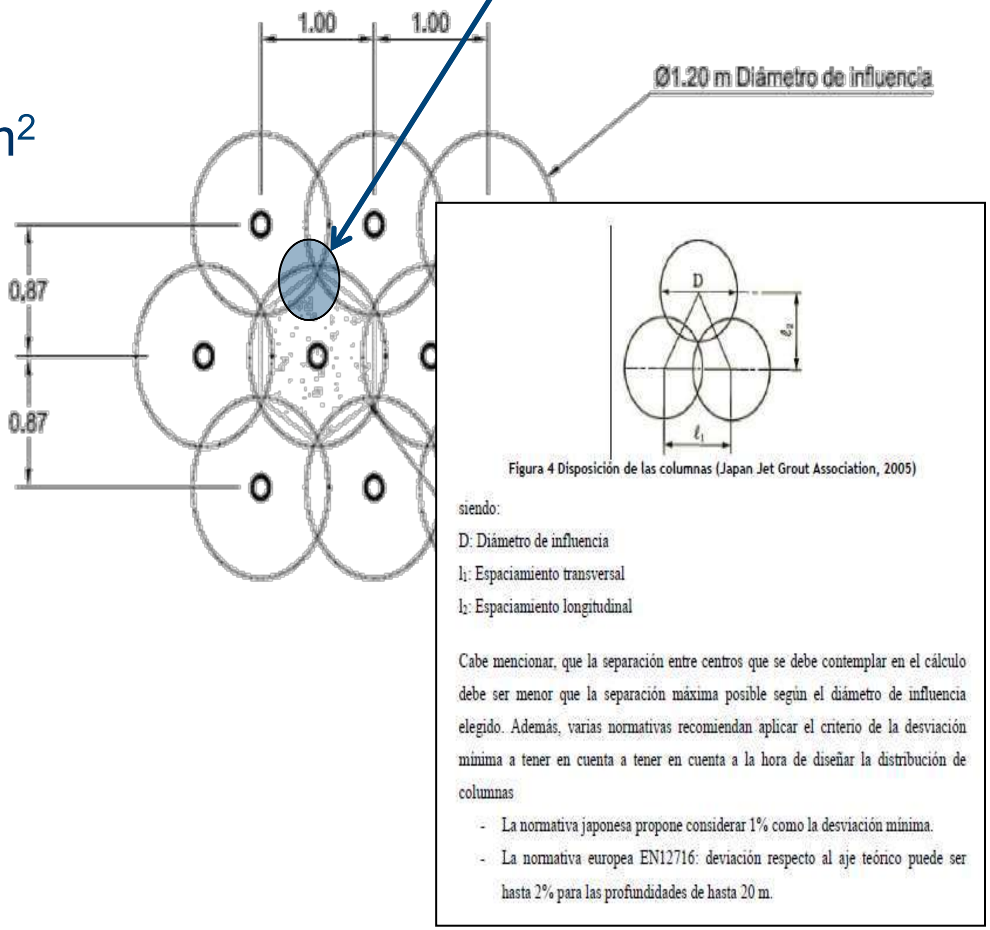


Figura 4 Disposición de las columnas (Japan Jet Grout Association, 2005)

siendo:

D: Diámetro de influencia

l_1: Espaciamiento transversal

l_2: Espaciamiento longitudinal

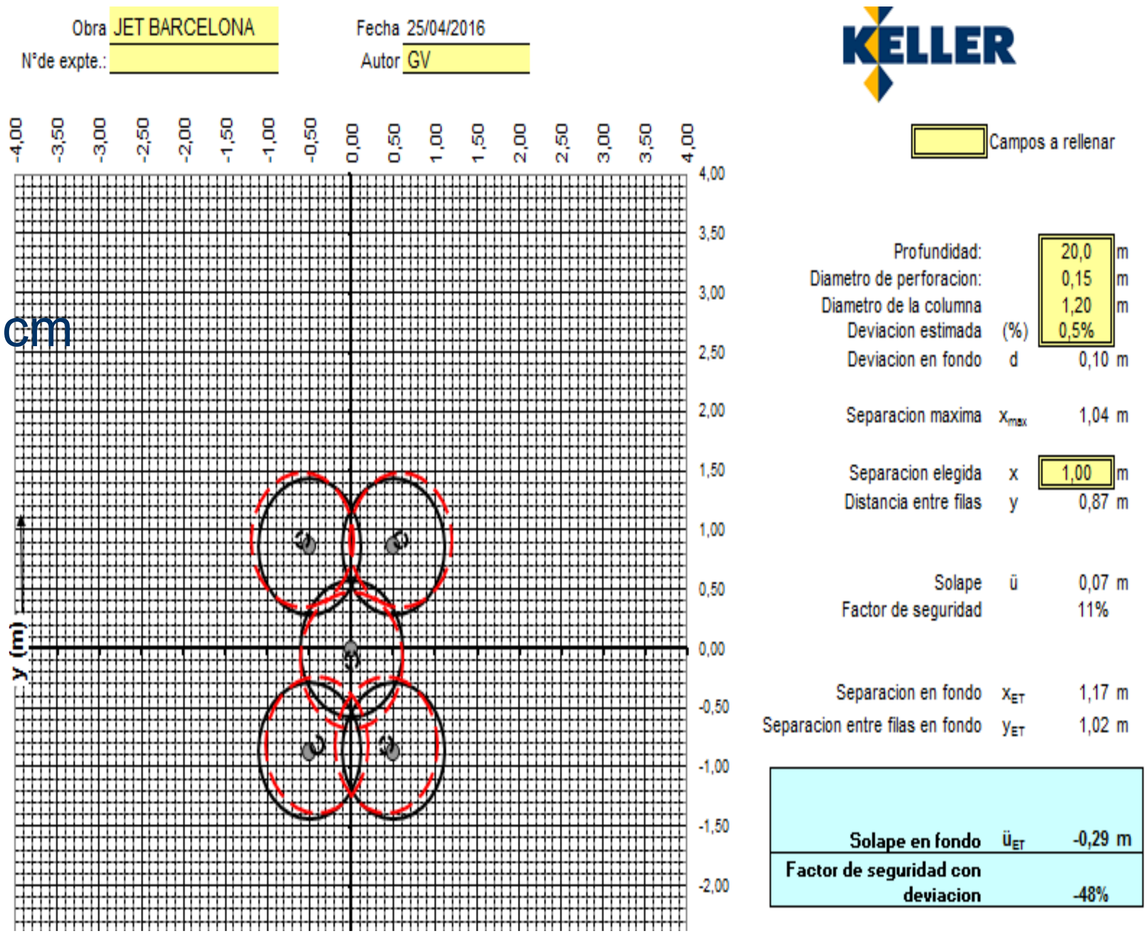
Cabe mencionar, que la separación entre centros que se debe contemplar en el cálculo debe ser menor que la separación máxima posible según el diámetro de influencia elegido. Además, varias normativas recomiendan aplicar el criterio de la desviación mínima a tener en cuenta a tener en cuenta a la hora de diseñar la distribución de columnas

- La normativa japonesa propone considerar 1% como la desviación mínima.
- La normativa europea EN12716: deviación respecto al aje teórico puede ser hasta 2% para las profundidades de hasta 20 m.

COLUMN DIAMETER

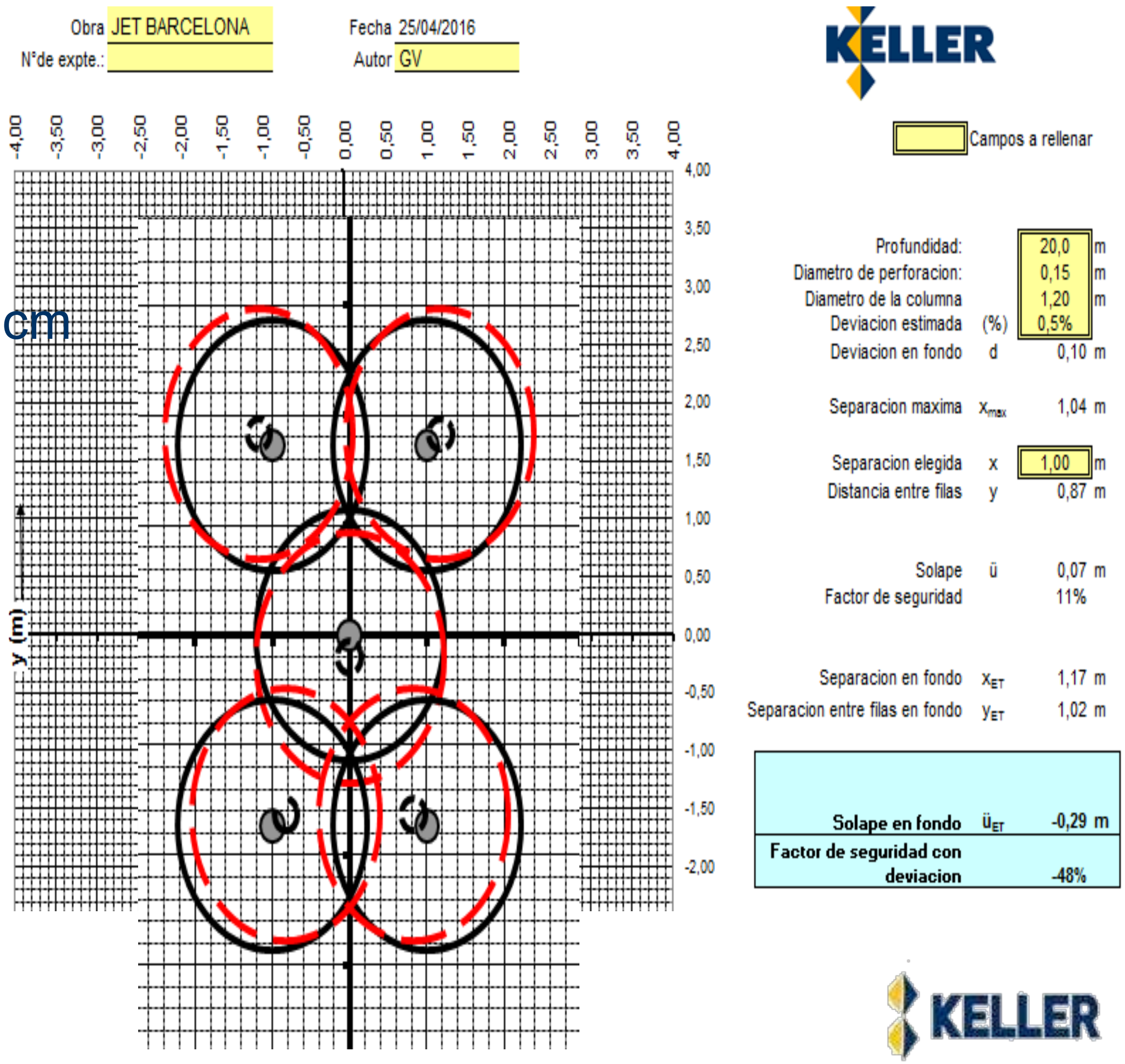
- Project initial solution:
  - dia.: 1,20 m
  - Grid: 1,0 x 1,0 m
  - Theoretical overlap: 6 cm

  - Deviation: 0,5%
  - Depth: 20m
  - Overlap: -29 cm



COLUMN DIAMETER

- Project initial solution:
  - dia.: 1,20 m
  - Grid: 1,0 x 1,0 m
  - Theoretical overlap: 6 cm
  - Deviation: 0,5%
  - Depth: 20m
  - Overlap: -29 cm



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COLUMN DIAMETER

– Keller solution:

Keller Cimentaciones, S.L.U.

ACCESOS AL AEROPUERTO DE BARCELONA

MEJORA DE SUELOS MEDIANTE JET GROUTING

ANEXO 2

PROPIEDADES DEL TERRENO MEJORADO, ELEMENTOS REDUCTORES DE PERMEABILIDAD Y CONTROL DE VERTICALIDAD

0	21.12.15	EMITIDO PARA REVISIÓN Y APROBACIÓN	JLAG	MAF	GV
REV	FECHA	Descripción de la revisión	Elaborado	Revisado	Aprobado

Keller Cimentaciones, S.L.U.

CLIENTE: UTE SACYR-FERROVIAL

EXPEDIENTE:	REV.
00150058671-PROPIEDADES Y VERTICALIDAD_V01_151221	1

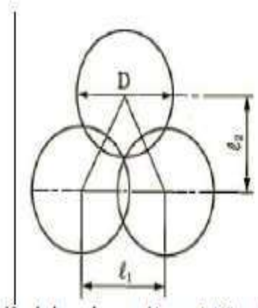


Figura 4 Disposición de las columnas (Japan Jet Grout Association, 2005)

siendo:

D: Diámetro de influencia

l_1: Espaciamiento transversal

l_2: Espaciamiento longitudinal

Cabe mencionar, que la separación entre centros que se debe contemplar en el cálculo debe ser menor que la separación máxima posible según el diámetro de influencia elegido. Además, varias normativas recomiendan aplicar el criterio de la desviación mínima a tener en cuenta a tener en cuenta a la hora de diseñar la distribución de columnas

- La normativa japonesa propone considerar 1% como la desviación mínima.
- La normativa europea EN12716: deviación respecto al aje teórico puede ser hasta 2% para las profundidades de hasta 20 m.

COLUMN DIAMETER

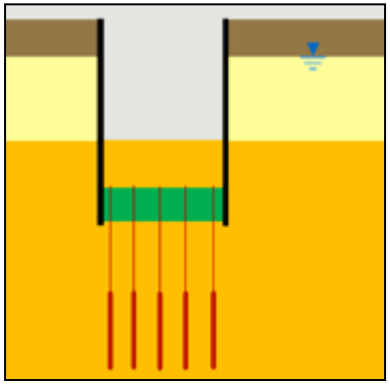
- Keller solution:
  - dia.: 1,80 m
    - Soil characteristics
    - Depth (up to 40 m)
    - Control deviation/verticality
    - Geometrical efficiency
    - Equipment
    - EXPERIENCE

COLUMN DIAMETER

- Keller solution:
  - dia.: 1,80 m (based on experience)

COLUMN DIAMETER

- Keller solution:
  - dia.: 1,80 m (based on experience)



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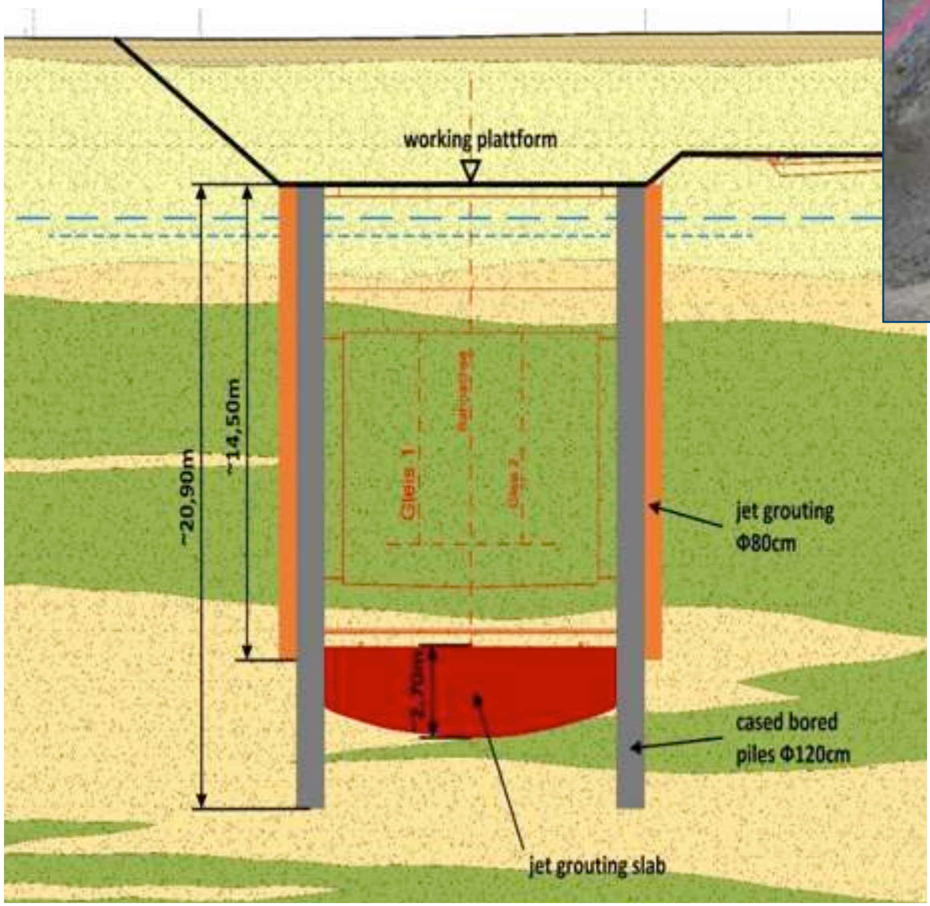
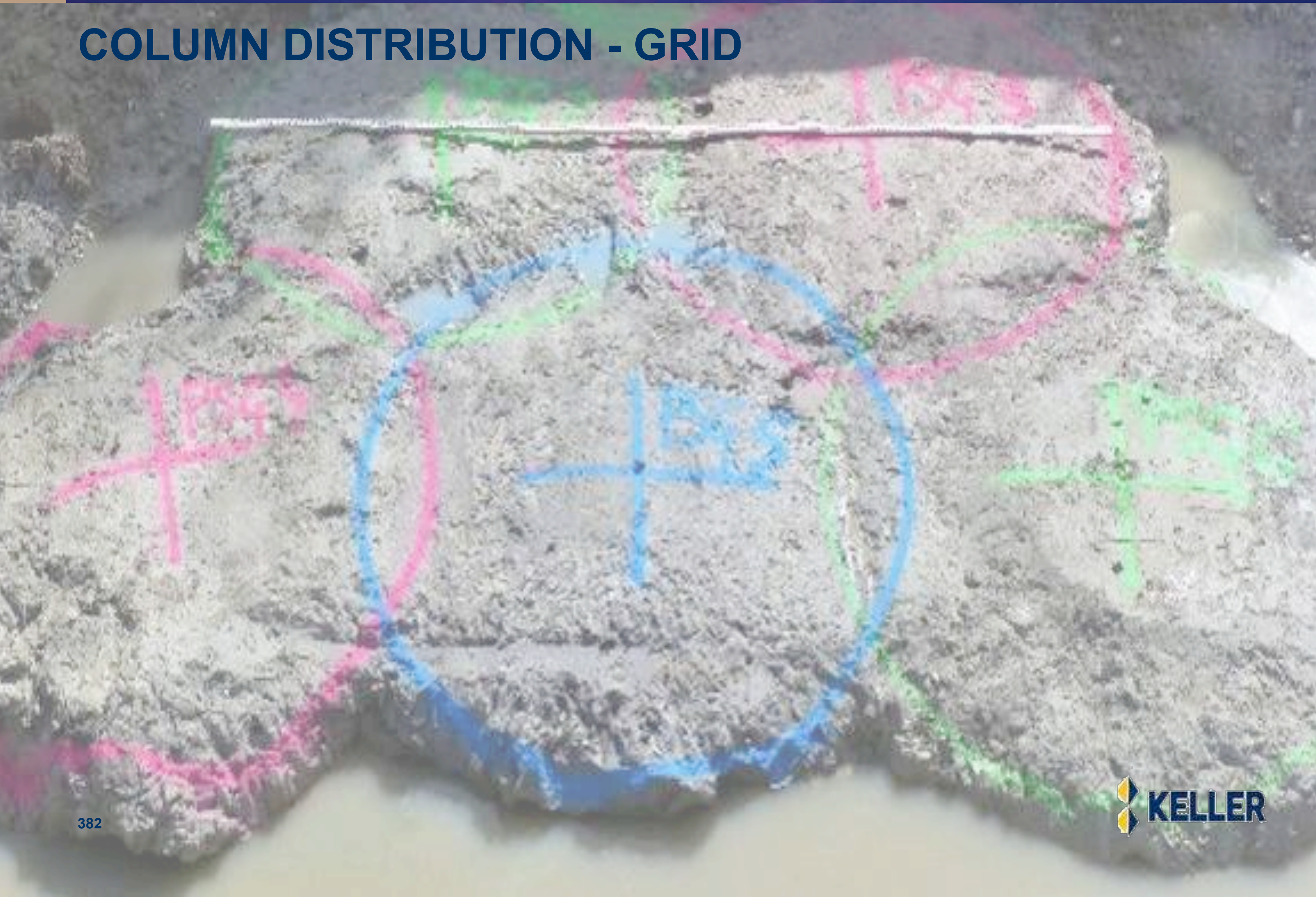
COLUMN DIAMETER

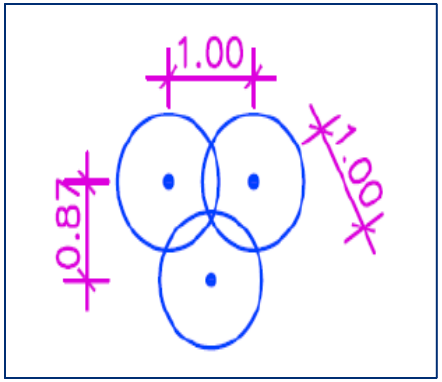
- Keller solution:
  - dia.: 1,80 m (based on experience)

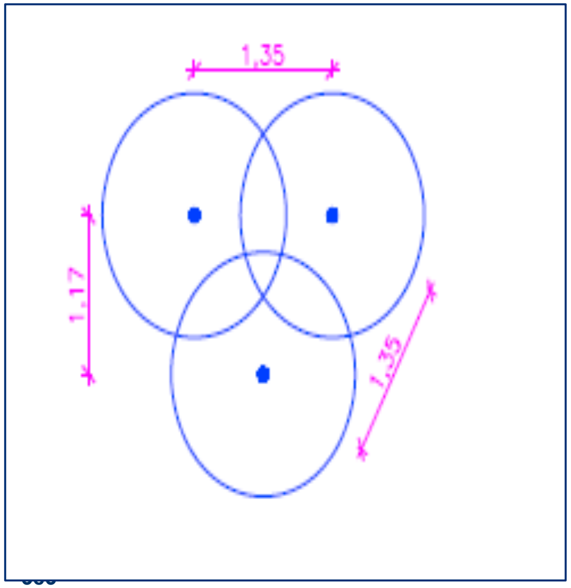


COLUMN DISTRIBUTION - GRID



COLUMN DISTRIBUTION - GRID



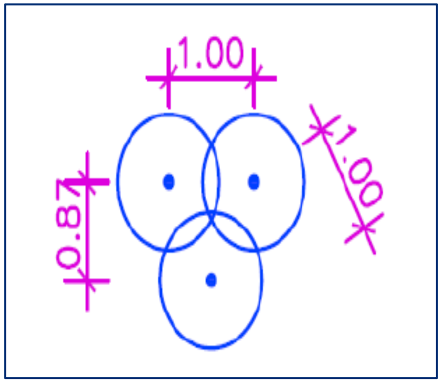


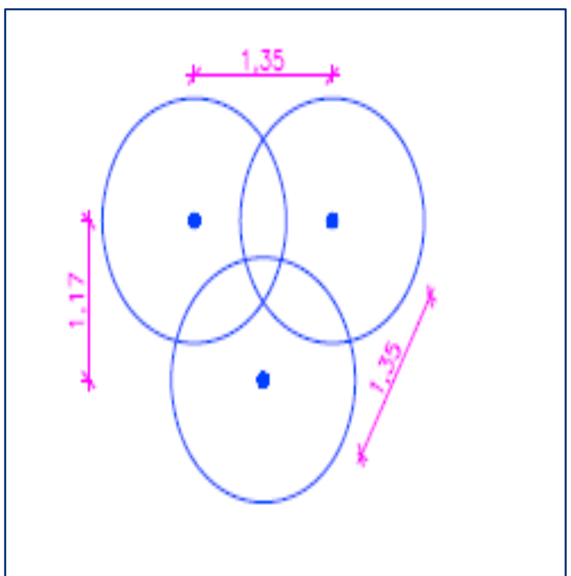
- Project solution: dia. 1,20 m
- Overlap: 6 cm

- Keller alternative solution: 1,80 m
- Permanent deviation control (incliJet)
- Overlap: 25-35 cm
- Deviation: 0,5-1%!

Figura 7. Control de verticalidad mediante Sistema propuesto.

COLUMN DISTRIBUTION - GRID





- Project solution: dia. 1,20 m
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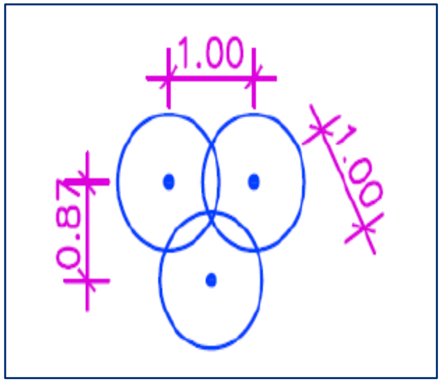
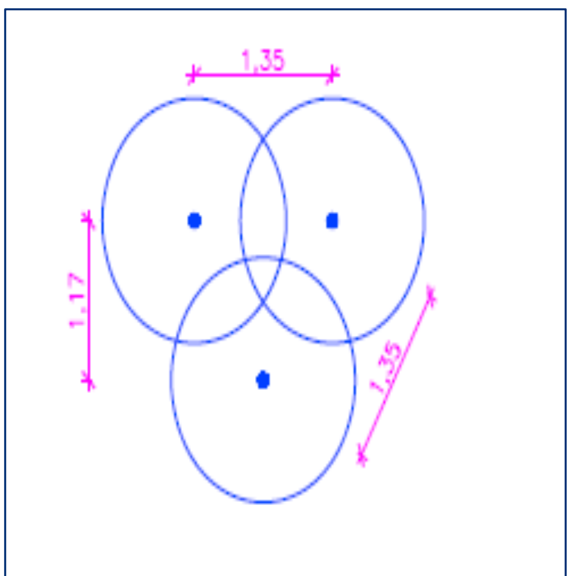
- Permanent deviation control (incliJet)
- Overlap: 25-35 cm
- Deviation: 0,5-1%!
  - Less critical points
  - Better control
  - Higher final quality

COLUMN DISTRIBUTION - GRID



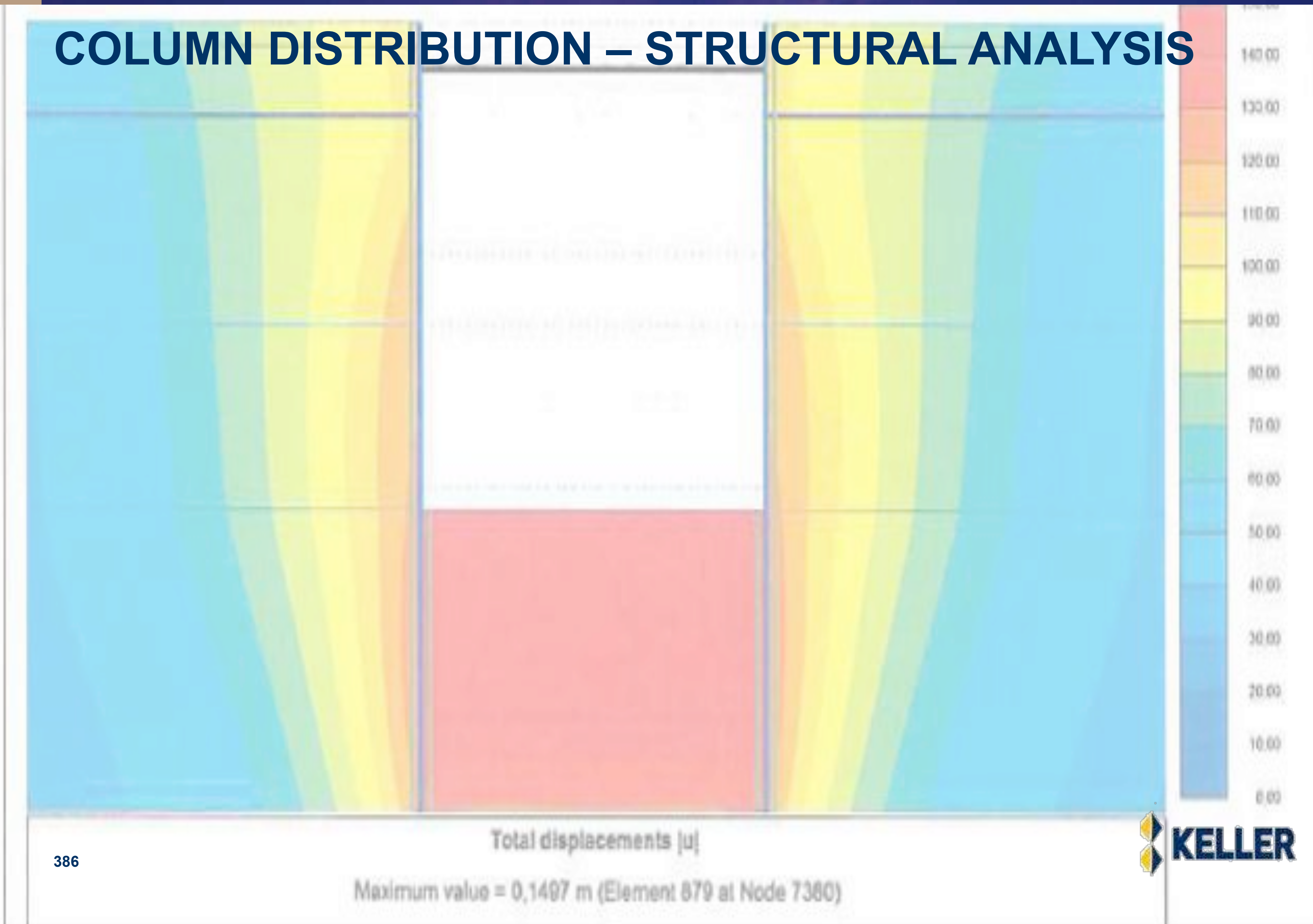


- Project solution: dia. 1,20 m
- Overlap: 6 cm
- <u>Point/Column influence: 0,87 m²</u>

- Keller alternative solution: 1,80 m
- Permanent deviation control (incliJet)
- Overlap: 25-35 cm
- <u>Point/Column influence: 1,7 m²</u>
- Optimization (production time and total number of columns: > 50%!

KELLER

COLUMN DISTRIBUTION – STRUCTURAL ANALYSIS



COLUMN DISTRIBUTION – STRUCTURAL ANALYSIS

- Technical specifications:
  - UCS: 3,50 Mpa
  - C ≥ 0,50 Mpa
  - E = 1.000 – 4.000 Mpa
  - Density ≥ 19 kN/m³

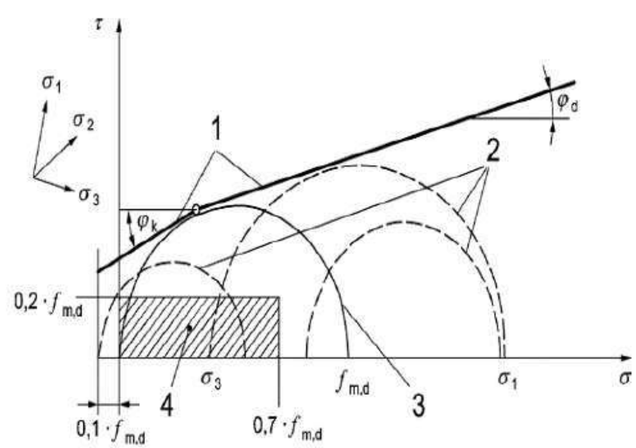
ESPECIFICACIONES DEL TAPÓN INFERIOR DE JET-GROUTING

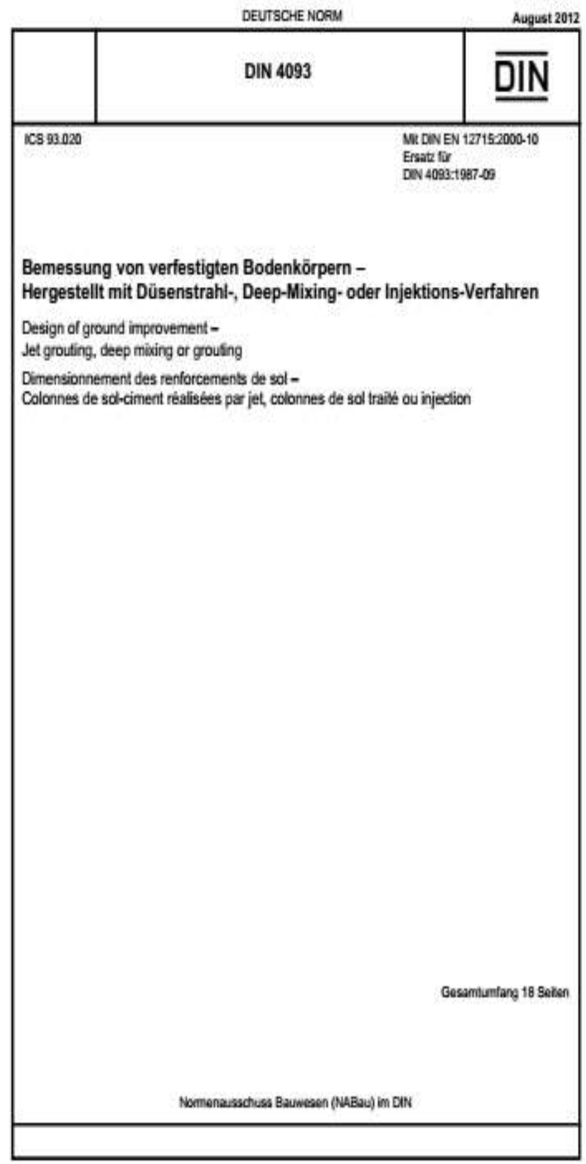
- RESISTENCIA CARACTERÍSTICA DE COMPRESIÓN = 3.50 MPa
- RESISTENCIA CARACTERÍSTICA DE TRACCIÓN = 0.60 MPa
- COHESIÓN ≥ 0.50 MPa
- MÓDULO DE ELASTICIDAD = 1000 MPa – 4000 MPa
- DENSIDAD ≥ 19 kN/m³

COLUMN DISTRIBUTION – STRUCTURAL ANALYSIS

– Technical specifications:
  - UCS: 3,50 Mpa
  - C ≥ 0,50 Mpa
  - E = 1.000 – 4.000 Mpa
  - Density ≥ 19 kN/m^3

DIN 4093:2012-08




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

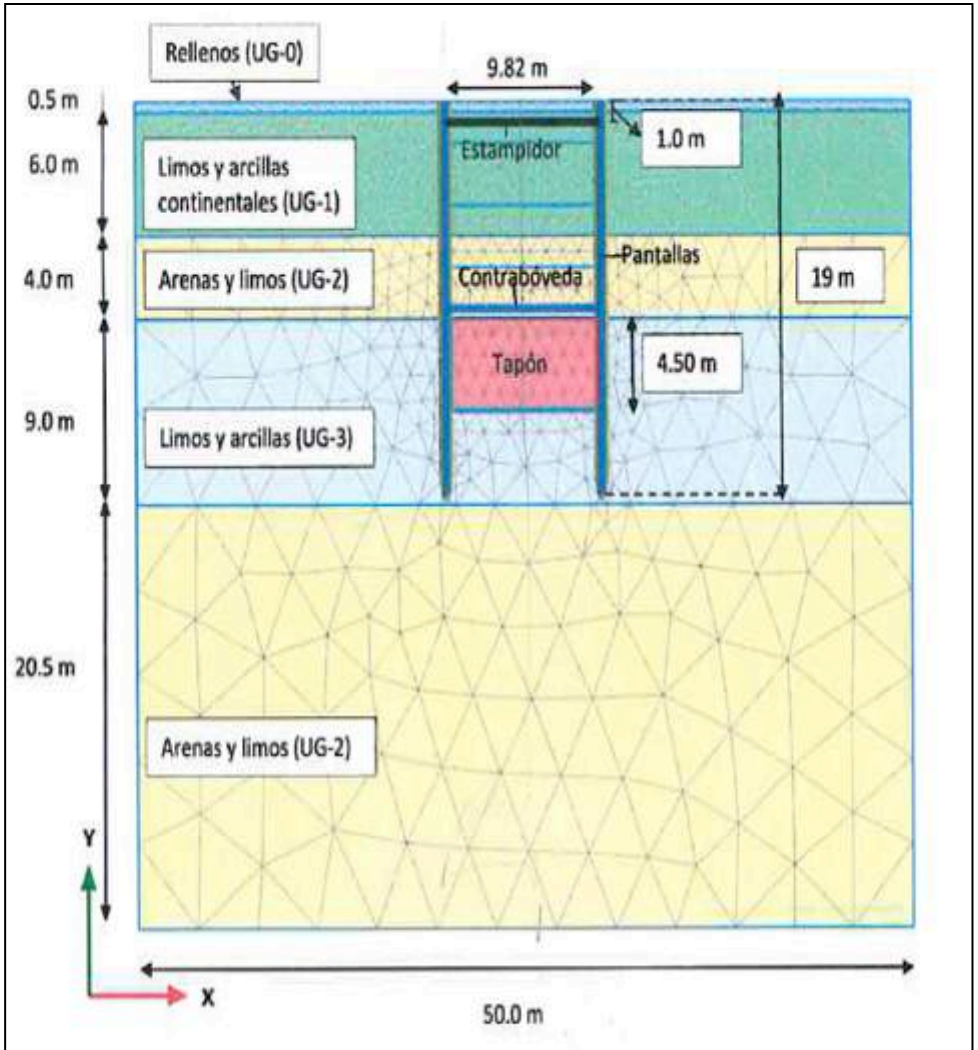
Design of ground improvement – Jet grouting, deep mixing or grouting

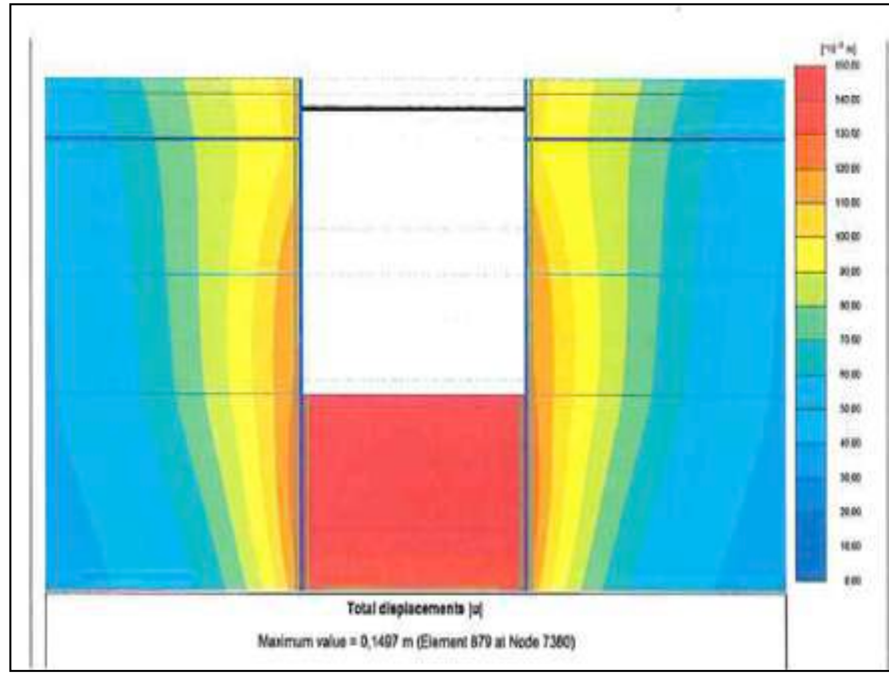
Dimensionnement des renforcements de sol – Colonnes de sol-ciment réalisées par jet, colonnes de sol traité ou injection

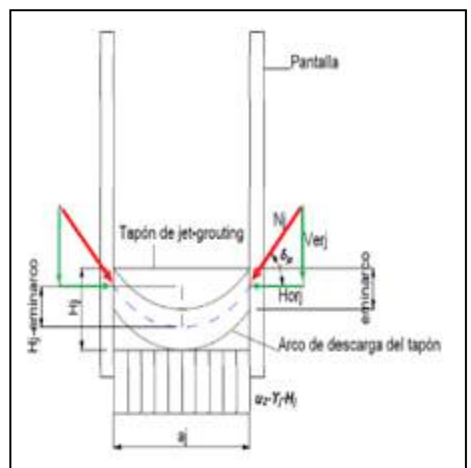
Gesamtumfang 18 Seiten

Normenausschuss Bauwesen (NABau) im DIN

COLUMN DISTRIBUTION – STRUCTURAL ANALYSIS

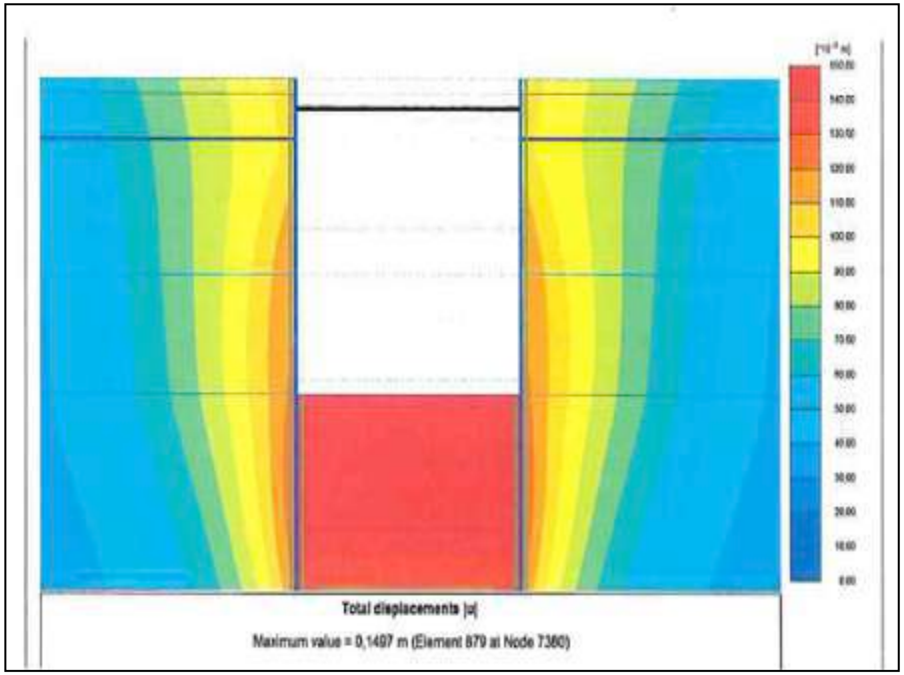


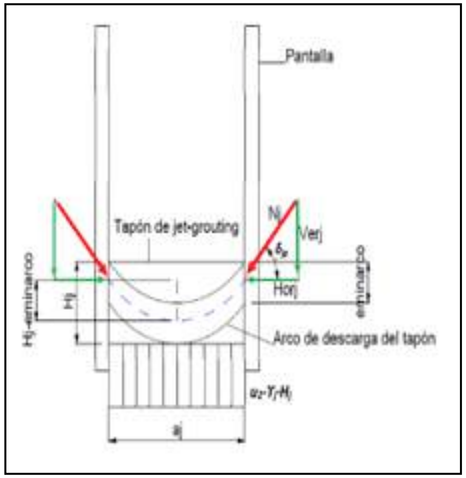




COLUMN DISTRIBUTION – STRUCTURAL ANALYSIS

- Result:
  - Optimization of the jet grouting sealing slab width
  - Optimization of DW





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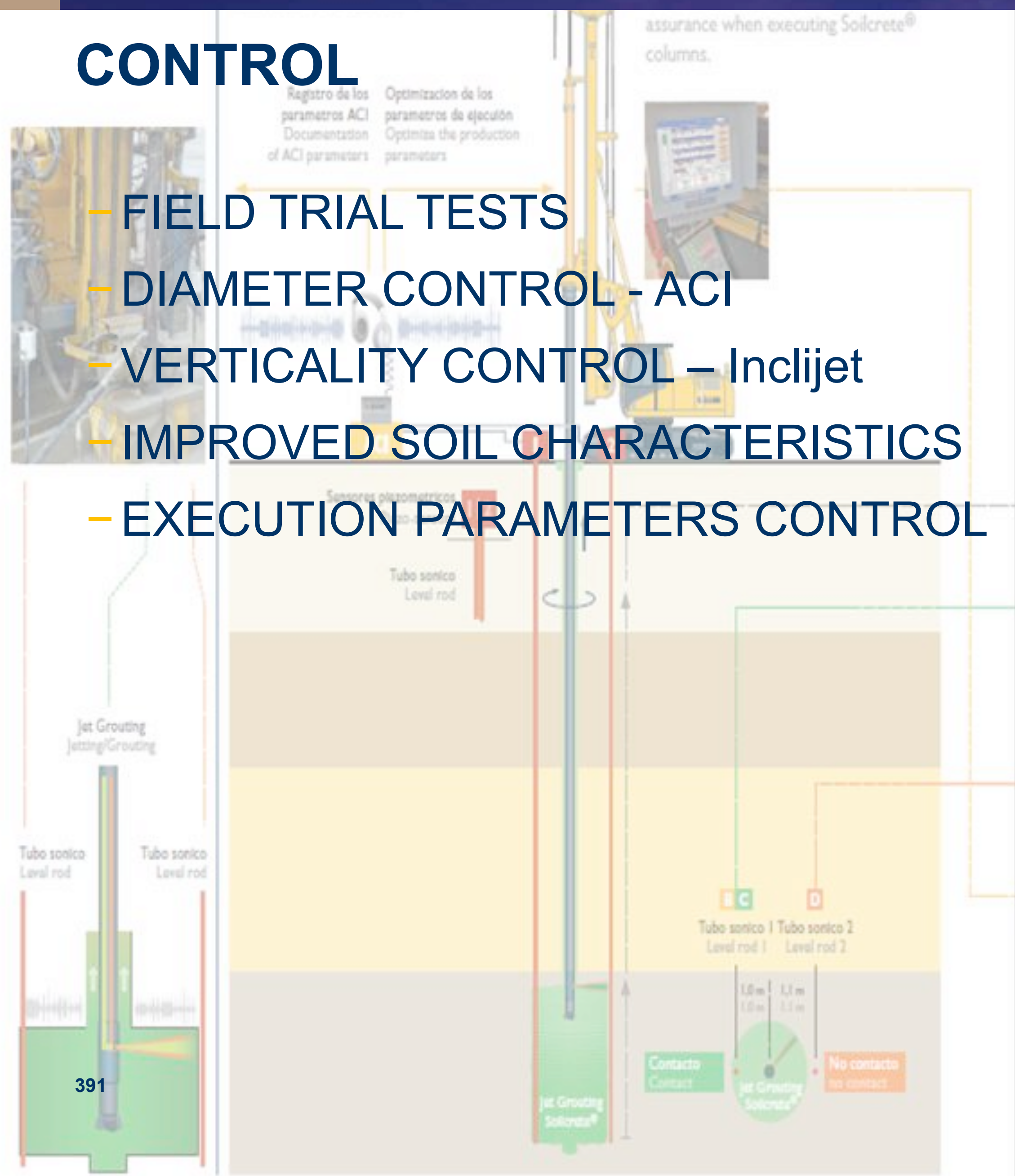
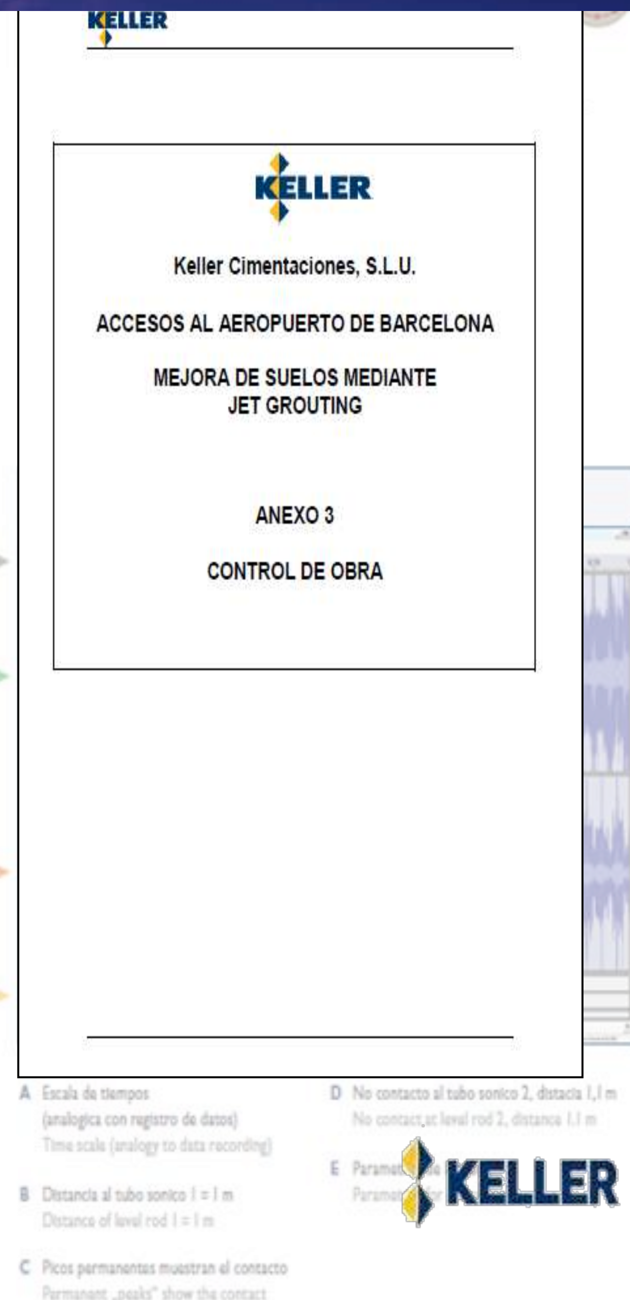
CONTROL

- FIELD TRIAL TESTS
- DIAMETER CONTROL - ACI
- VERTICALITY CONTROL – Inclijet
- IMPROVED SOIL CHARACTERISTICS
- EXECUTION PARAMETERS CONTROL





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Keller Cimentaciones, S.L.U.

ACCESOS AL AEROPUERTO DE BARCELONA

MEJORA DE SUELOS MEDIANTE JET GROUTING

ANEXO 3

CONTROL DE OBRA

FIELD TRIAL TESTS

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FIELD TRIAL TESTS

- Various field trial tests were performed:
  - Different areas of the project (tunnel, runway area, intermodal station)
  - Different depths
  - Different soil conditions

- Objective:
  - To verify jet grouting diameter and mechanical characteristics
  - To control and verify deviation range
  - To establish optimum execution parameters (monitor, nozzles, pressure, flow rate, w/c, etc.)

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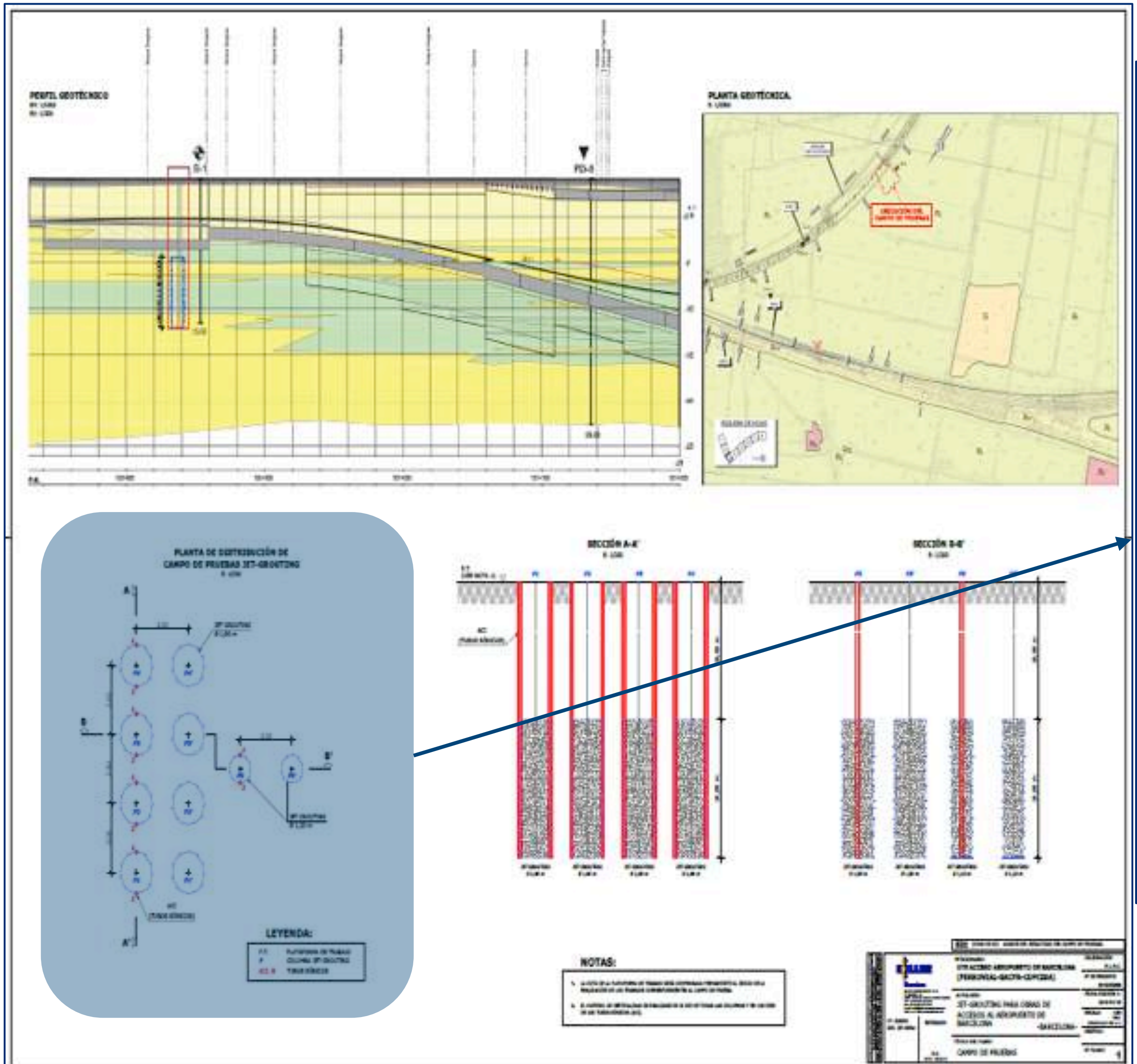
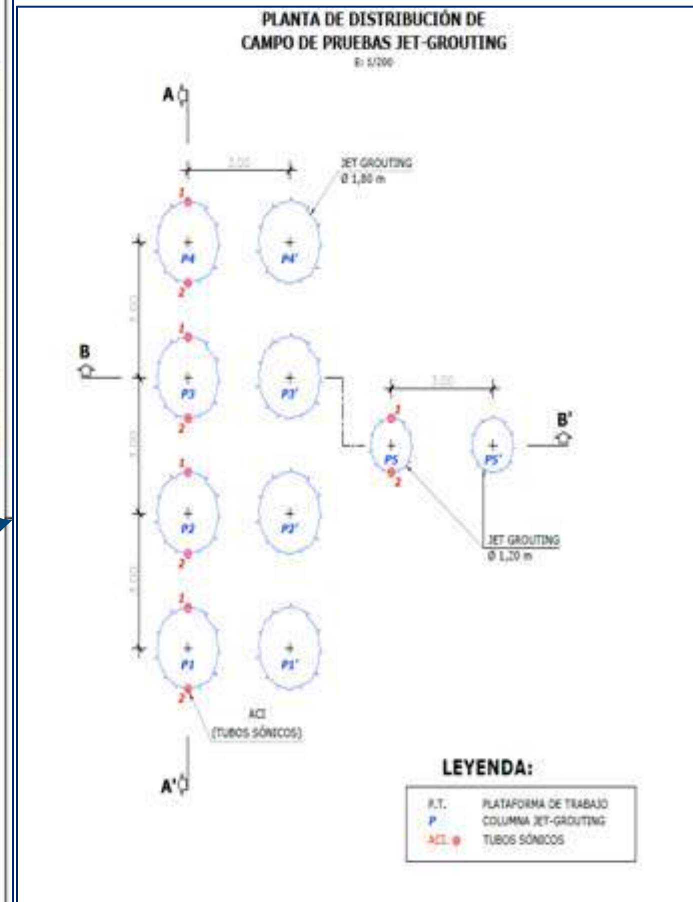
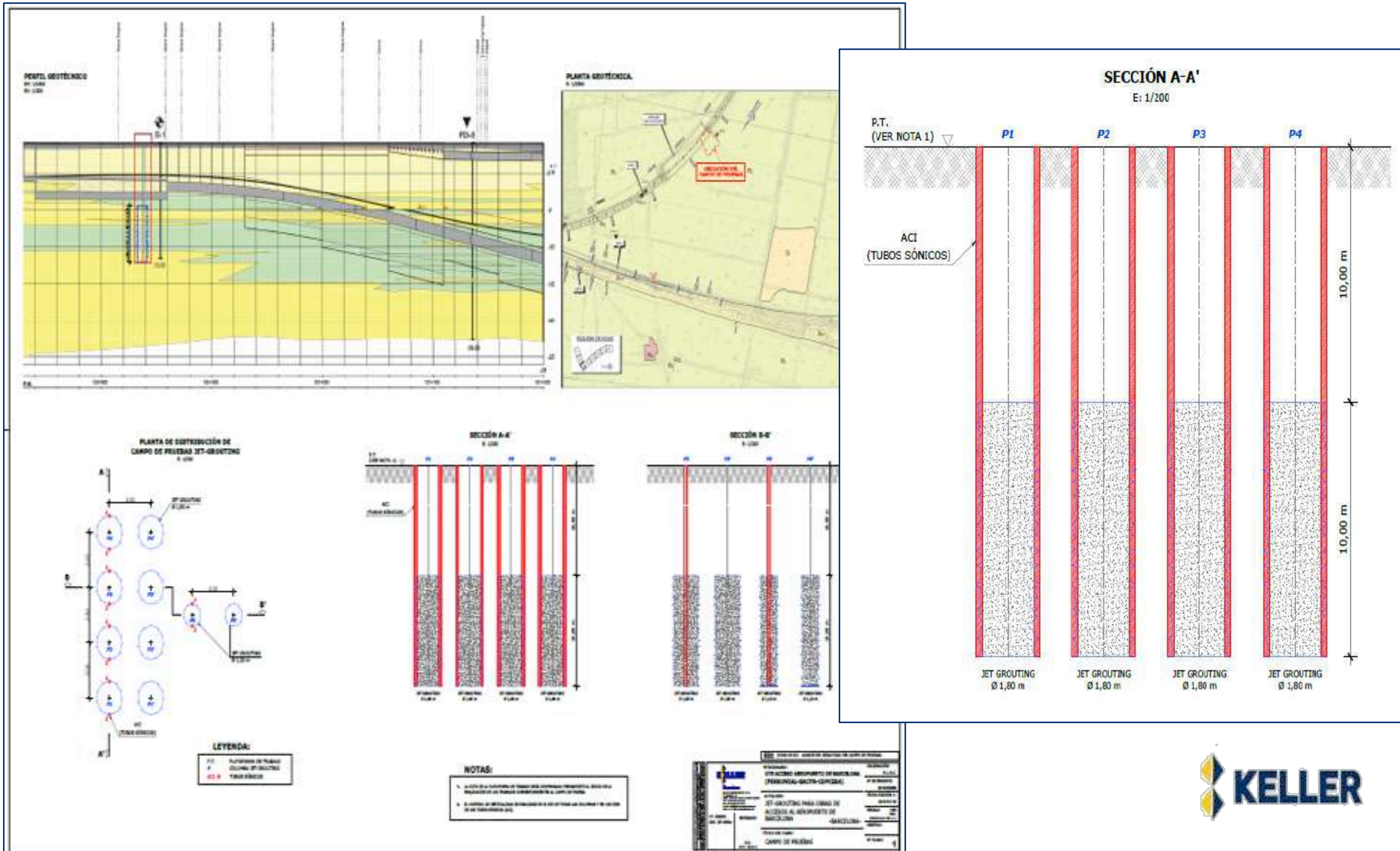
FIELD TRIAL TESTS





FIELD TRIAL TESTS



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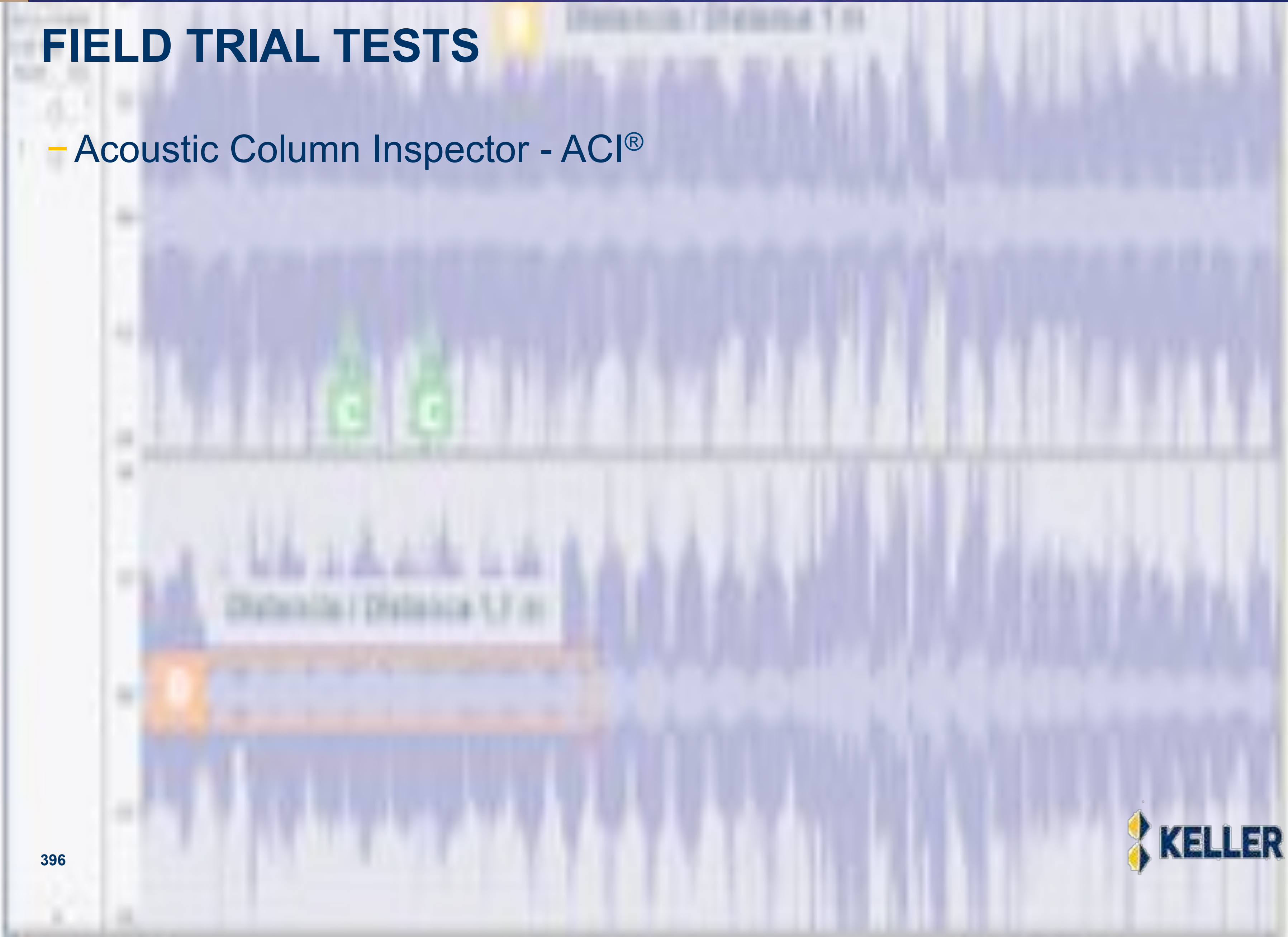
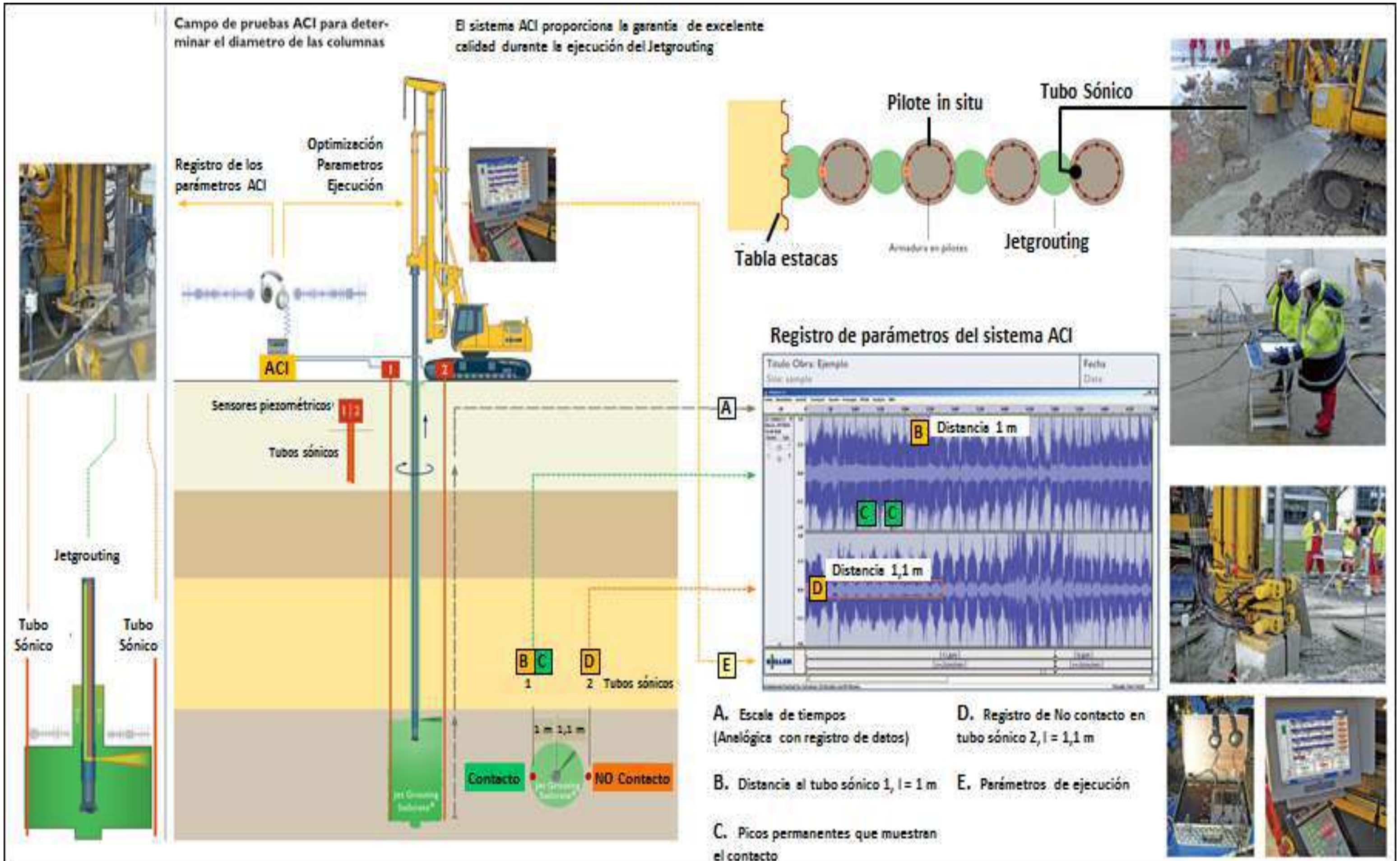
FIELD TRIAL TESTS

- Acoustic Column Inspector - ACI®



FIELD TRIAL TESTS

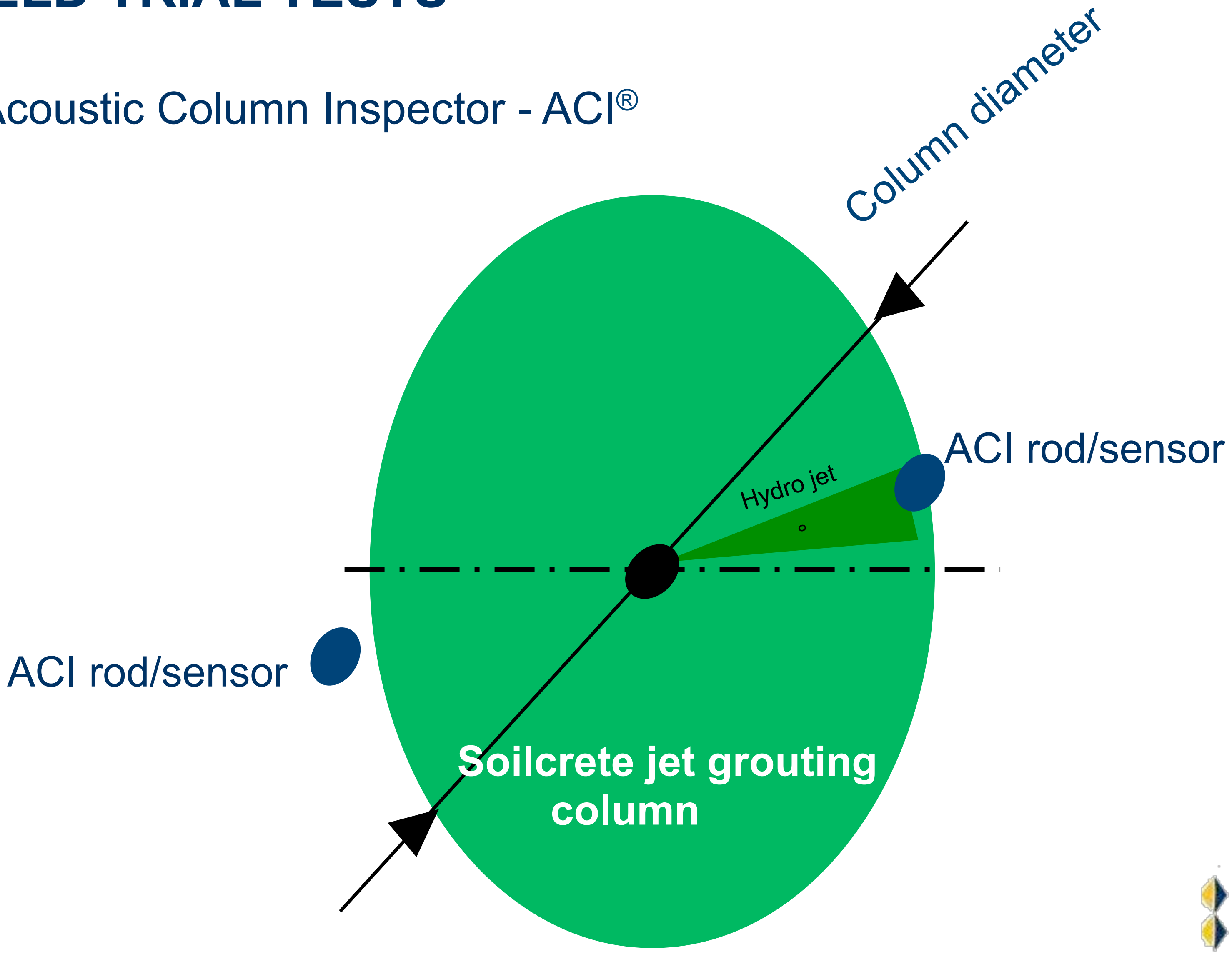
– Acoustic Column Inspector - ACI®



KELLER

FIELD TRIAL TESTS

- Acoustic Column Inspector - ACI®



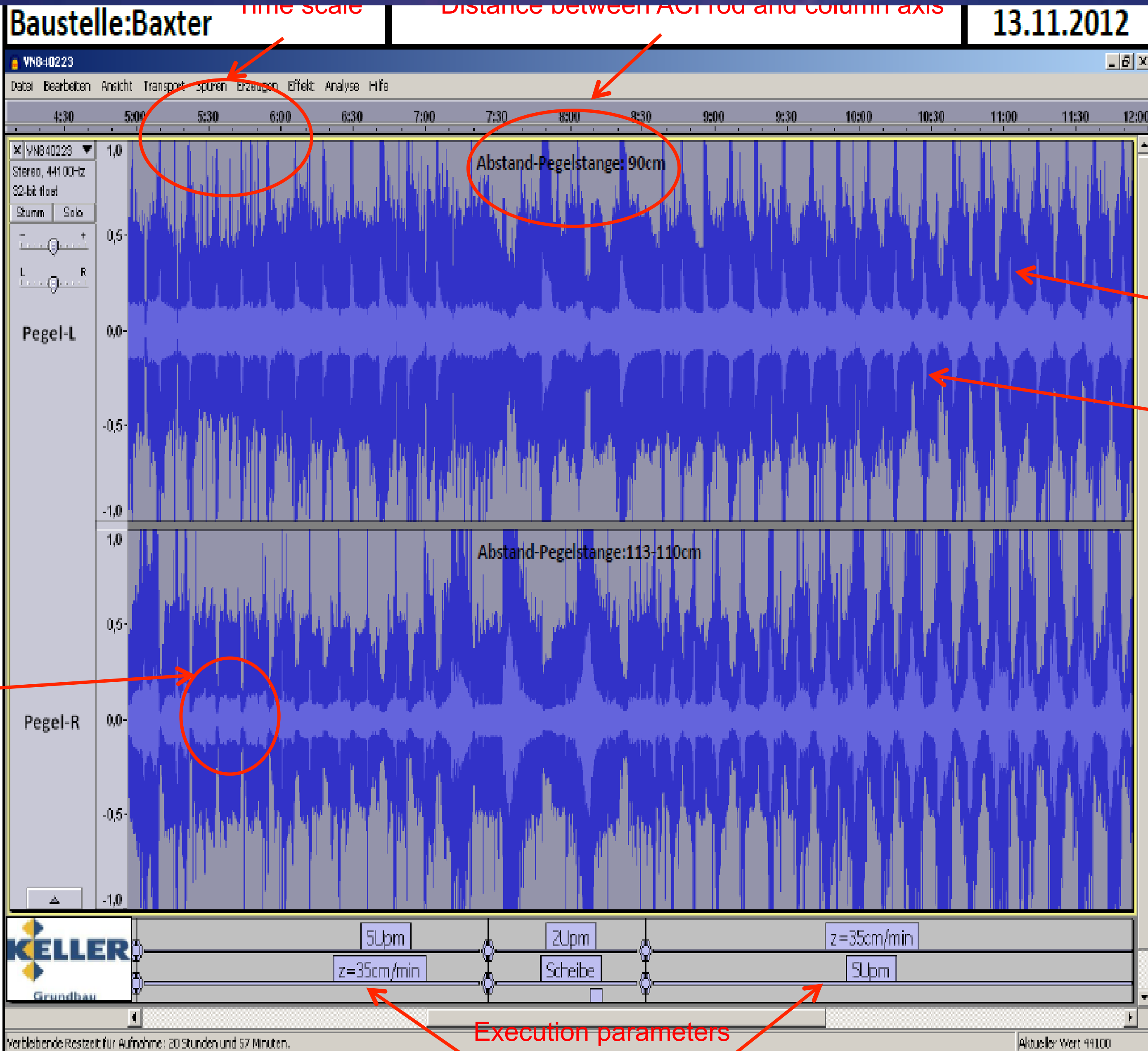
FIELD TRIAL TESTS

- Acoustic Column Inspector - ACI®

FIELD TRIAL TESTS

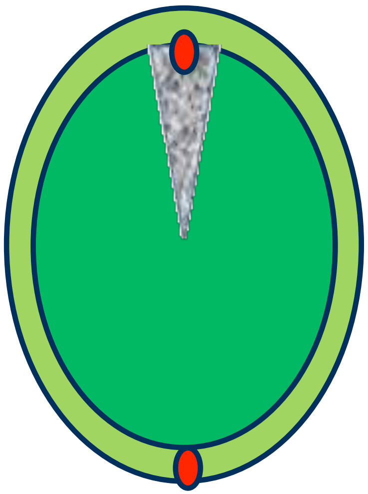
– Acoustic Column Inspector - ACI®

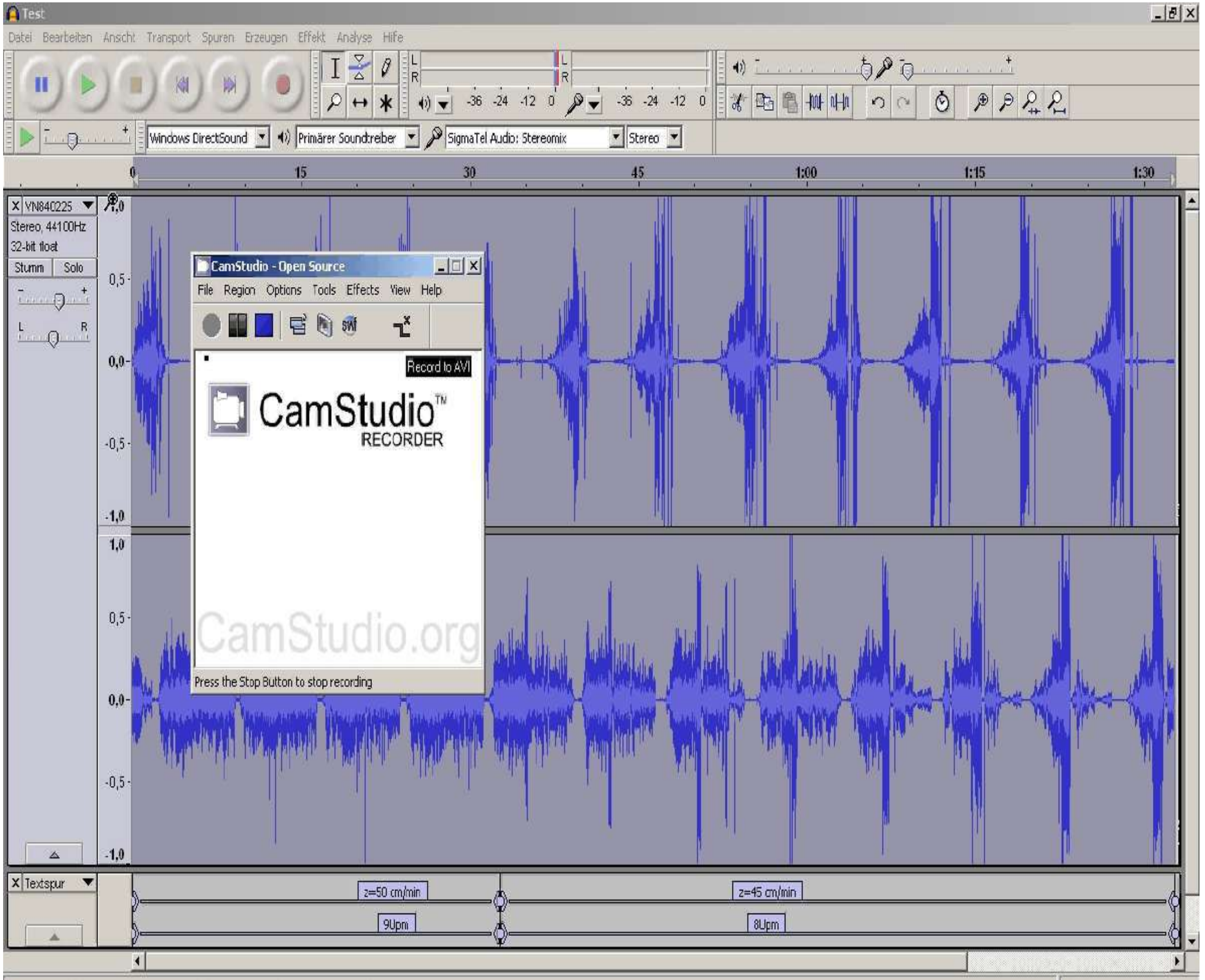
KELLER

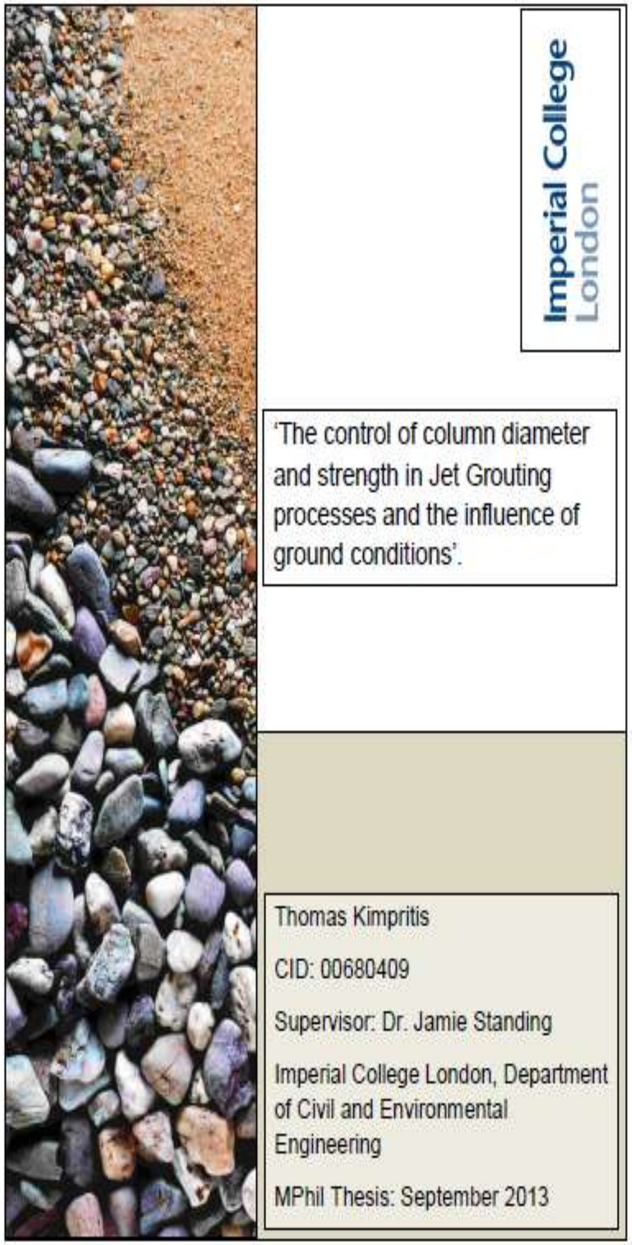


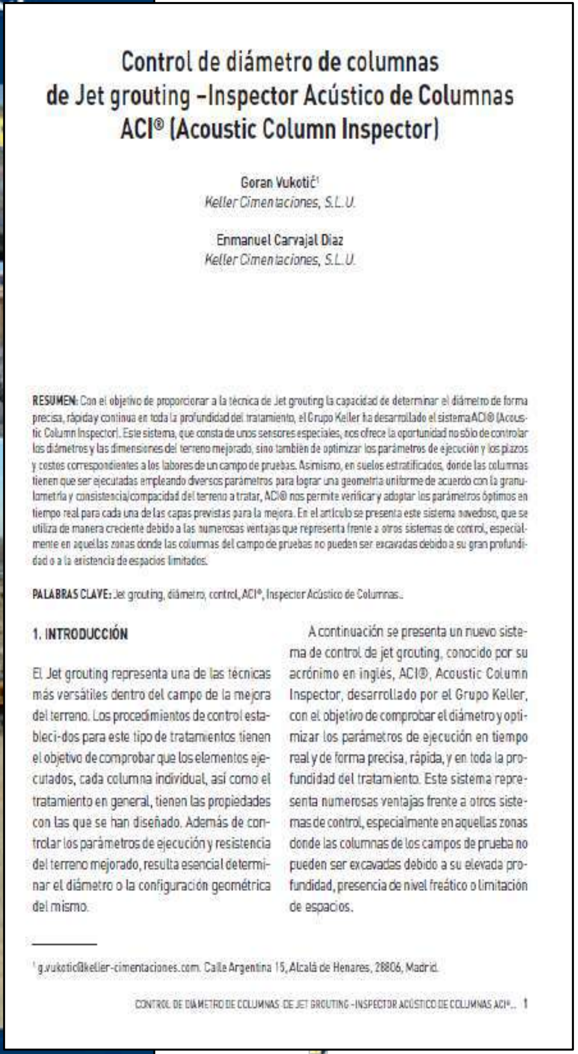
Permanent peaks demonstrate contact between jet and ACI

No contact




Test
Datei Bearbeiten Ansicht Transport Spuren Erzeugen Effekt Analyse Hilfe
Windows DirectSound
Primärer Soundtreiber
SigmaTel Audio: Stereomix
Stereo
VN840225
Stereo, 44100Hz
32-bit float
Stumm Solo
CamStudio - Open Source
File Region Options Tools Effects View Help
Record to AVI
CamStudio
RECORDER
CamStudio.org
Press the Stop Button to stop recording
Textspur
z=50 cm/min
9Upm
z=45 cm/min
8Upm





Control de diámetro de columnas de Jet grouting –Inspector Acústico de Columnas ACI® (Acoustic Column Inspector)

Goran Vukotić[1]
Keller Cimentaciones, S.L.U.

Enmanuel Carvajal Díaz
Keller Cimentaciones, S.L.U.

RESUMEN: Con el objetivo de proporcionar a la técnica de Jet grouting la capacidad de determinar el diámetro de forma precisa, rápida y continua en toda la profundidad del tratamiento, el Grupo Keller ha desarrollado el sistema ACI® (Acoustic Column Inspector). Este sistema, que consta de unos sensores especiales, nos ofrece la oportunidad no sólo de controlar los diámetros y las dimensiones del terreno mejorado, sino también de optimizar los parámetros de ejecución y los plazos y costos correspondientes a los labores de un campo de pruebas. Asimismo, en suelos estratificados, donde las columnas tienen que ser ejecutadas empleando diversos parámetros para lograr una geometría uniforme de acuerdo con la granulometría y consistencia/compacidad del terreno a tratar, ACI® nos permite verificar y adoptar los parámetros óptimos en tiempo real para cada una de las capas previstas para la mejora. En el artículo se presenta este sistema novedoso, que se utiliza de manera creciente debido a las numerosas ventajas que representa frente a otros sistemas de control, especialmente en aquellas zonas donde las columnas del campo de pruebas no pueden ser excavadas debido a su gran profundidad o a la existencia de espacios limitados.

PALABRAS CLAVE: Jet grouting, diámetro, control, ACI®, Inspector Acústico de Columnas..

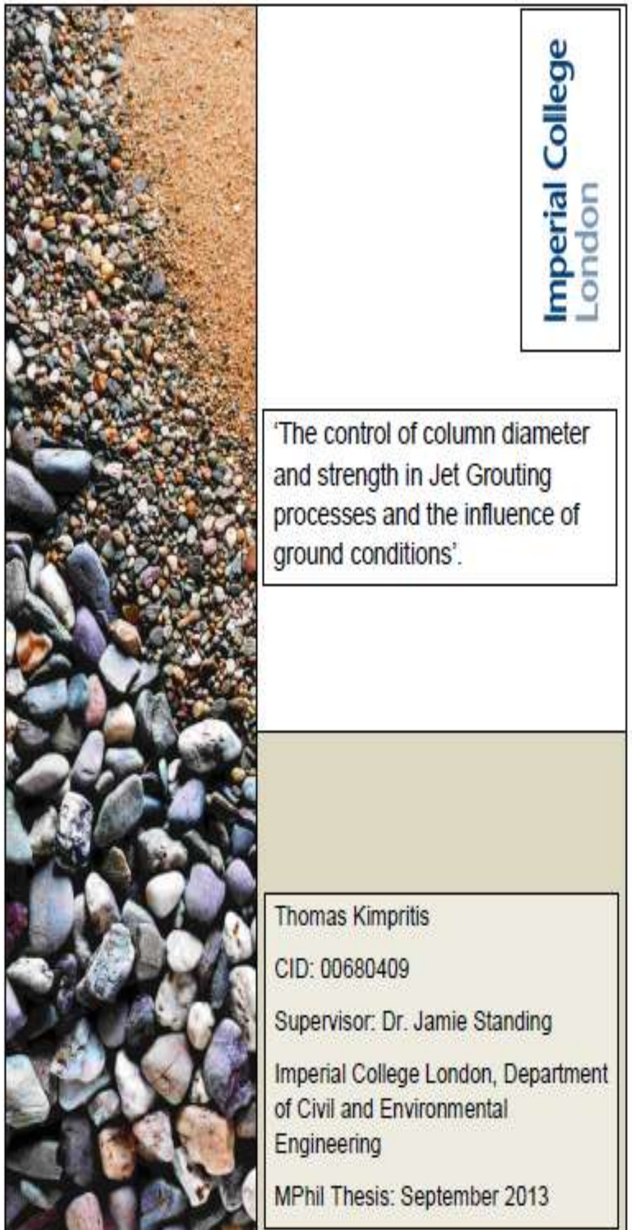
1. INTRODUCCIÓN

El Jet grouting representa una de las técnicas más versátiles dentro del campo de la mejora del terreno. Los procedimientos de control estableci-dos para este tipo de tratamientos tienen el objetivo de comprobar que los elementos ejecutados, cada columna individual, así como el tratamiento en general, tienen las propiedades con las que se han diseñado. Además de controlar los parámetros de ejecución y resistencia del terreno mejorado, resulta esencial determinar el diámetro o la configuración geométrica del mismo.

A continuación se presenta un nuevo sistema de control de jet grouting, conocido por su acrónimo en inglés, ACI®, Acoustic Column Inspector, desarrollado por el Grupo Keller, con el objetivo de comprobar el diámetro y optimizar los parámetros de ejecución en tiempo real y de forma precisa, rápida, y en toda la profundidad del tratamiento. Este sistema representa numerosas ventajas frente a otros sistemas de control, especialmente en aquellas zonas donde las columnas de los campos de prueba no pueden ser excavadas debido a su elevada profundidad, presencia de nivel freático o limitación de espacios.

[1] g.vukotic@keller-cimentaciones.com. Calle Argentina 15, Alcalá de Henares, 28806, Madrid.

CONTROL DE DIÁMETRO DE COLUMNAS DE JET GROUTING –INSPECTOR ACÚSTICO DE COLUMNAS ACI®... 1


Imperial College London

'The control of column diameter and strength in Jet Grouting processes and the influence of ground conditions'.

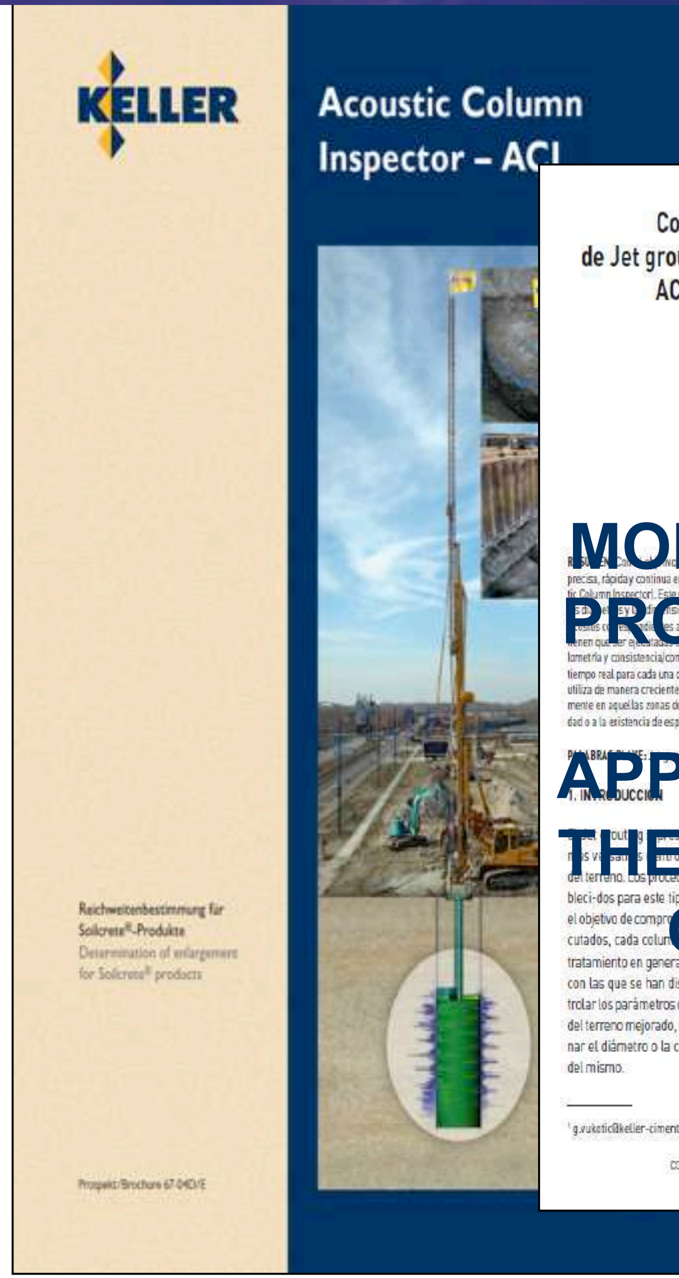
Thomas Kimpritis

CID: 00680409

Supervisor: Dr. Jamie Standing

Imperial College London, Department of Civil and Environmental Engineering

MPhil Thesis: September 2013




Control de diámetro de columnas de Jet grouting –Inspector Acústico de Columnas ACI® (Acoustic Column Inspector)

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CONTROL DE DIÁMETRO DE COLUMNAS DE JET GROUTING –INSPECTOR ACÚSTICO DE COLUMNAS ACI®... 1

MORE THAN 400 PROJECTS WITH THE APPLICATION OF THE ACI SYSTEM CONTROL

FIELD TRIAL TESTS

– Verticality control - IncliJet®

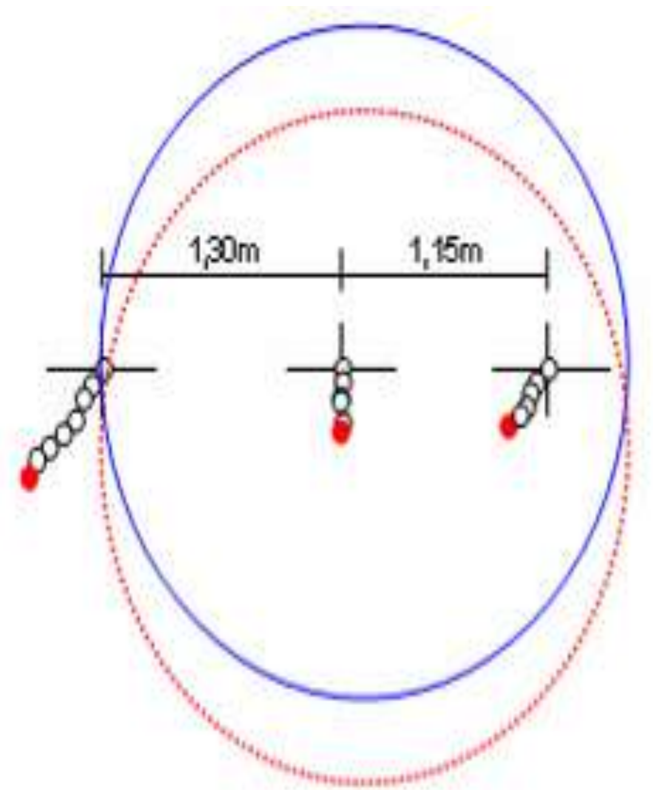
- Fundamental for permeability reduction by jet grouting and for trial tests (diameter)

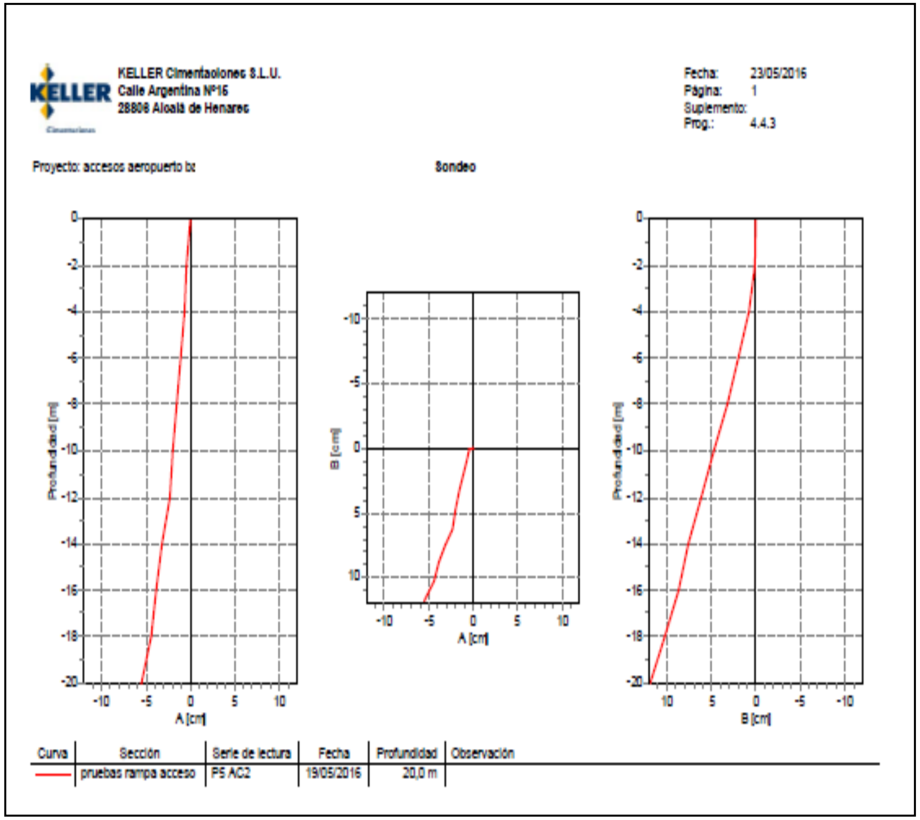
- Keller controlled:
- All trial columns
- > 50% of executed columns in general (> 7.000 measurements)

KELLER

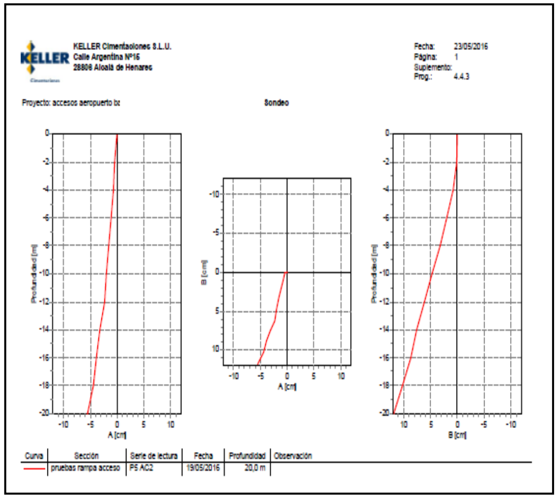
FIELD TRIAL TESTS

- Verticality control - IncliJet®





FIELD TRIAL TESTS



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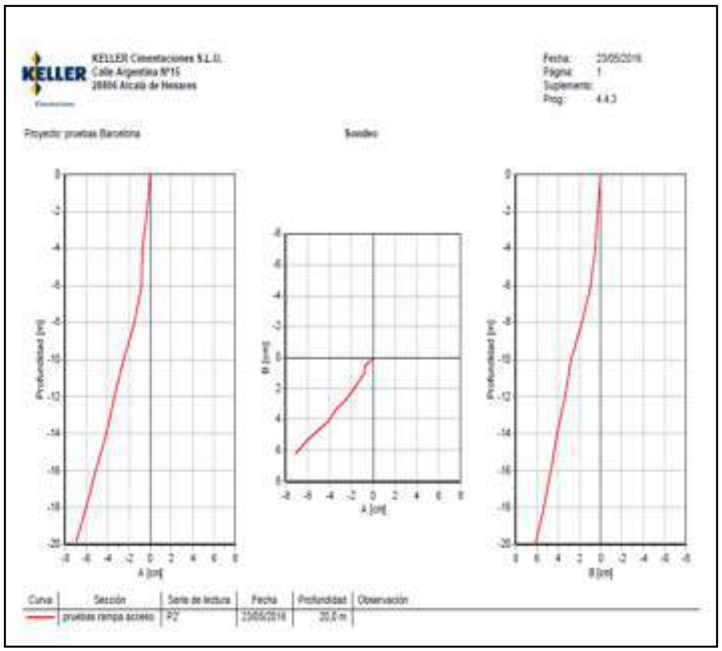
FIELD TRIAL TESTS

- Verticality control - IncliJet®
- Medium deviation: 0,5%



KELLER — Jet grouting – Campo de prueba

Columna	Punto	Profundidad (m)	Desviación (cm)	Desviación (%)
P4	AC1	20	14,74	0,74%
		10	6,61	0,66%
	AC2	20	5,33	0,27%
		10	2,74	0,27%
P3	AC1	20	9,49	0,47%
		10	2,54	0,25%
	AC2	20	9,73	0,49%
		10	2,19	0,22%
P2	AC1	20	6,26	0,31%
		10	1,53	0,15%
	AC2	20	2,03	0,10%
		10	0,68	0,07%
P1	AC1	20	8,39	0,42%
		10	1,72	0,17%
	AC2	20	2,34	0,12%
		10	1,29	0,13%
P4	EJE	20	0,25	0,01%
		10	0,85	0,09%
P3	eje	20	8,65	0,43%
		10	1,75	0,17%
P2	eje	20	18,04	0,90%
		10	5,66	0,57%
P1	eje	20	16,13	0,81%
		10	2,87	0,29%
P5	eje	20	13,05	0,65%
		10	3,30	0,33%
	AC1	20	12,52	0,63%
		10	5,06	0,51%
	AC2	20	14,12	0,71%
		10	5,50	0,55%
P4'	eje	20	19,69	0,98%
		10	4,90	0,49%
P3'	eje	20	10,03	0,50%
		10	4,37	0,44%
P2'	eje	20	11,76	0,59%
		10	4,49	0,45%
P1'	eje	20	11,54	0,58%
		10	5,80	0,58%
P5'	eje	20	12,56	0,63%
		10	4,83	0,48%

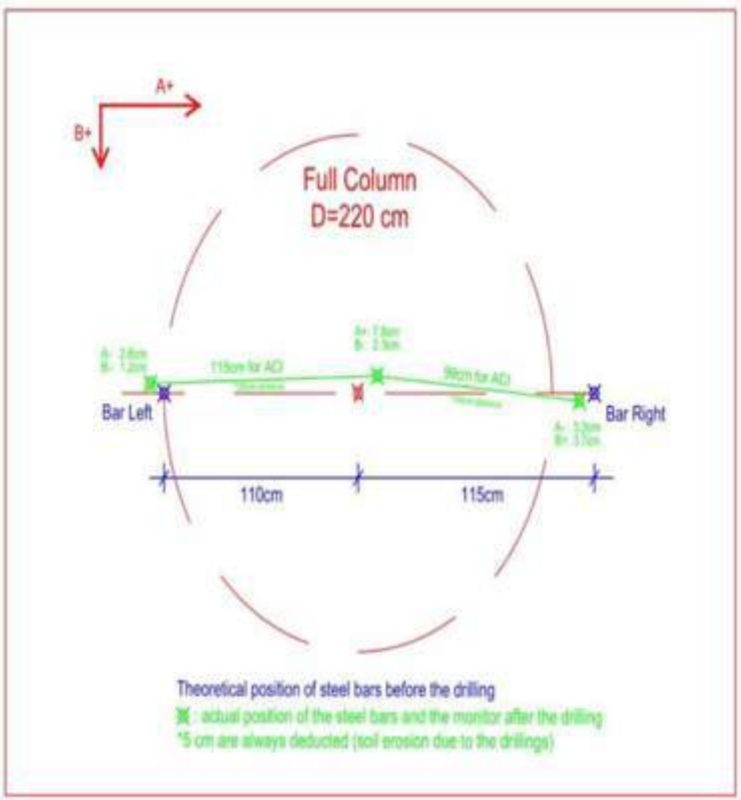
Tabla 1. Desviaciones medidas en las perforaciones realizadas

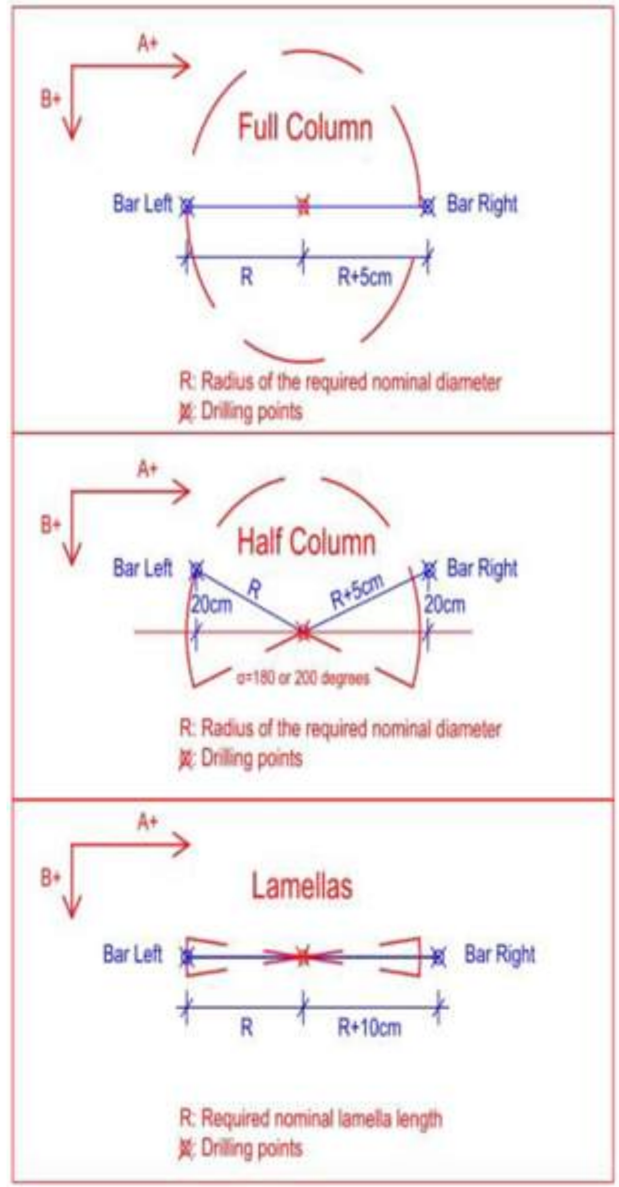
Proyecto: Jet grouting en los Acceso al Aeropuerto de Barcelona
Informe Técnico
Keller – Cimentaciones, S.L.U.
Page 14 of 43

KELLER

FIELD TRIAL TESTS

- Final ACI tube/sensors position

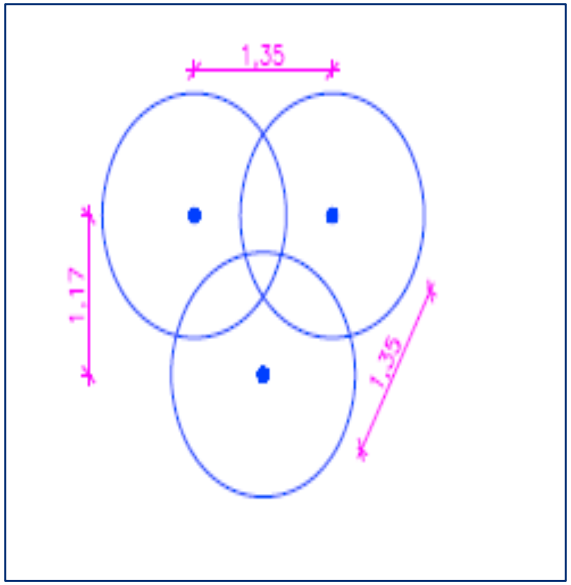




KELLER

FIELD TRIAL TESTS

- Verticality control - IncliJet®
- Medium deviation: 0,5%
- Grid: 1,35 x 1,35 m triangular



KELLER

FIELD TRIAL TESTS

- Verticality control - IncliJet®
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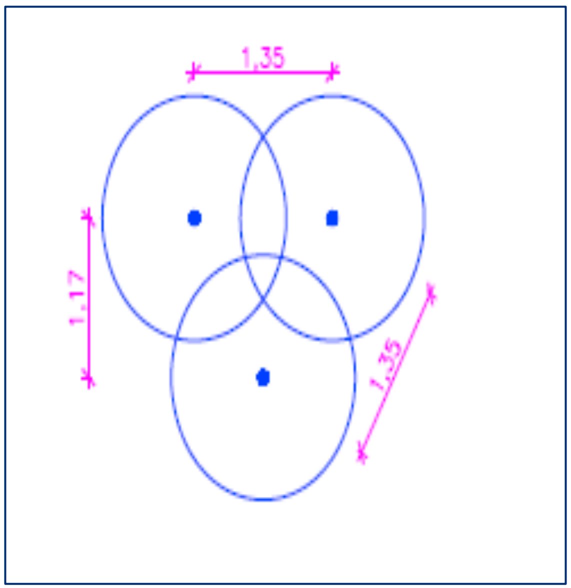
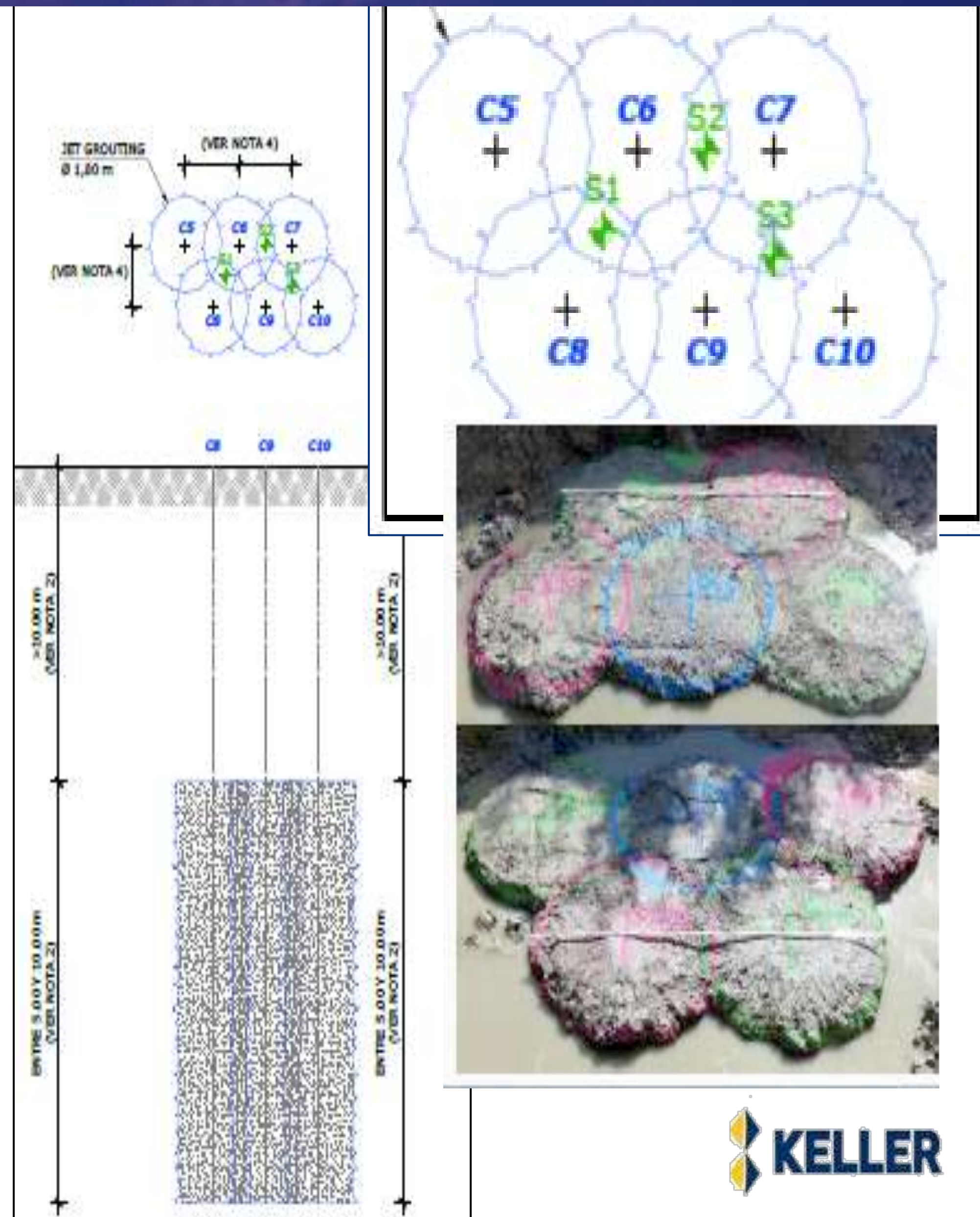




IMPROVED SOIL CHARACTERISTICS

- Technical specifications:
  - UCS: 3,50 Mpa
  - C ≥ 0,50 Mpa
  - E = 1.800 – 4.000 Mpa
  - Density ≥ 19 kN/m^3
- Wet samples (fresh jet grouting)
- Core drilling (aprox. 28 days)

KELLER

IMPROVED SOIL CHARACTERISTICS

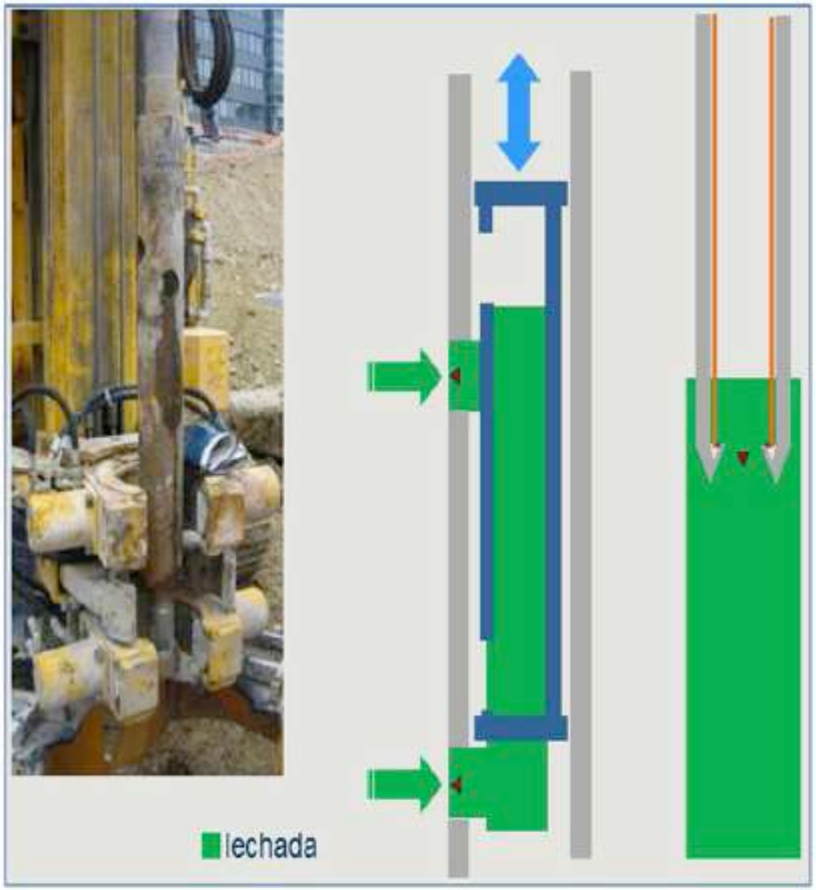
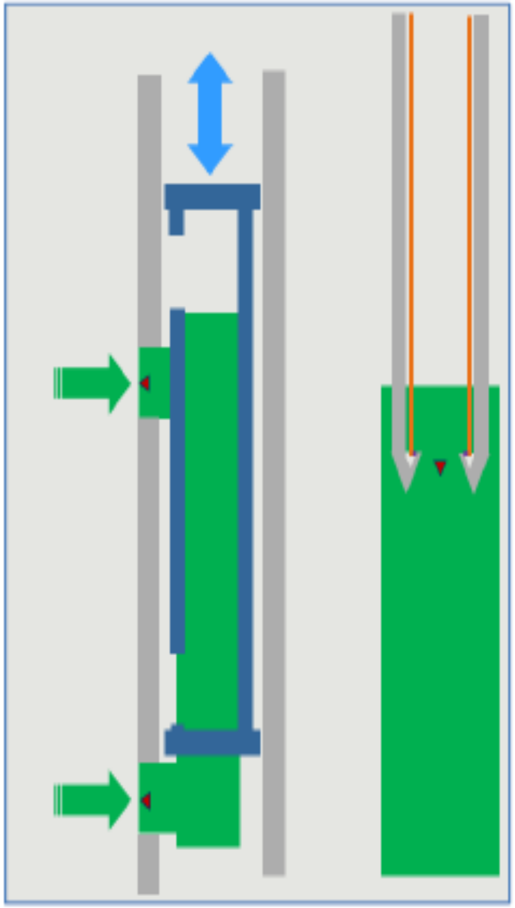


Figura 6. Herramientas para toma de muestras en fresco.

– Wet samples (fresh jet grouting)

IMPROVED SOIL CHARACTERISTICS



- Wet samples (fresh jet grouting)

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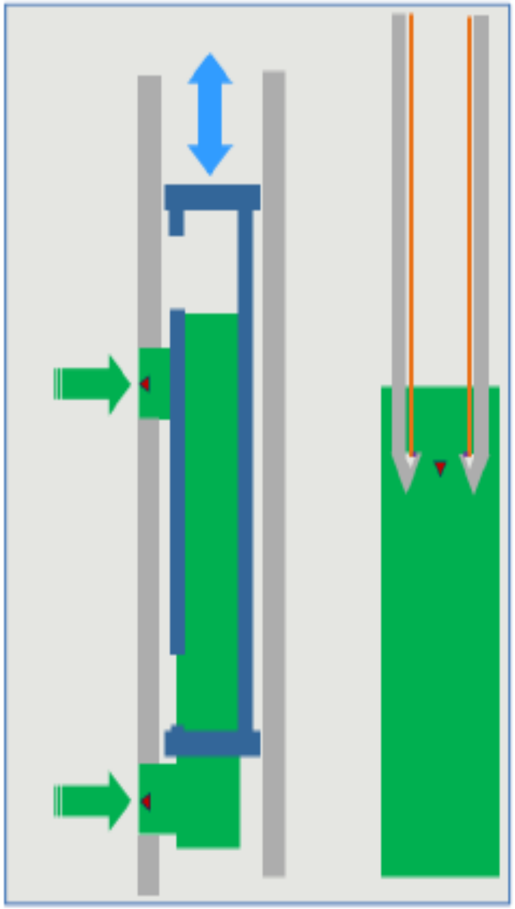
IMPROVED SOIL CHARACTERISTICS

– Wet samples (fresh jet grouting)



LECHADAS DE CEMENTO
UNE-EN 447:1996

Nº de expediente	1613078 - 0.1 -
Nº registro	LC.08 483
Cliente	KELLERTERRA, S.L.
Peticionario	R. JAVIER LECHUGA GUERRER
Nombre de la obra	LAV LA SAGRERA
Dirección obra	K-07-K-72-K
Población	—

DATOS DE LA LECHADA

Unidad de obra controlada	COLUMNA DE PRUEBA (P 1), COTA 13 METROS
Tipo de muestra	JET GROUTING
Fabricante	—
Resistencia especif.	— kp/cm² = — Mpa
Fecha fabricación	04/09/09
Hora de amasado	—
Temp. ambiente	— °C
Temp. lechada	— °C
Muestra tomada por	EL PETICIONARIO
En	AMASADORA EN LA OBRA
Fecha	04/09/09
Hora	—
Muestra recepcionada en	OBRA
Fecha	08/09/09
[illegible]	104820/09
Probetas confeccionadas en	—
Fecha	—
Hora	—
Temperatura	— °C

DETERMINACIÓN DE LAS RESISTENCIAS MECÁNICAS SOBRE PROBETAS PRISMÁTICAS DE 4 x 4 x 16 cm

DATOS DEL ENSAYO			RESULTADOS UNE-EN 445:96 y UNE-EN 196-1:96				
			RESISTENCIA (MPa)				
			FLEXOTRACCIÓN		COMPRESIÓN		
			TENSIÓN DE ROTURA		TENSIÓN DE ROTURA		
Refer. probeta	Probeta ensayada (saturada ó seca)	Edad de la probeta en el ensayo (días)	Valor individual	Valor medio	Valores individuales		Valor medio
1	SATURADA	10	1,20	1,25	5,96	6,05	6,0
2	"	14	1,73	1,75	6,20	6,15	6,2
3	"	28	1,85	1,90	6,30	6,25	6,2
4	"	42	0,00	0,00	0,00	0,00	0,0
5	"	60	0,00	0,00	0,00	0,00	0,0
6	"	100	0,00	0,00	0,00	0,00	0,0

Notas :

PAYMACotas - (Cornellà)

Registro de ensayos — Fecha: 16/10/2009

RESULTADOS CORRESPONDIENTES A LA MUESTRA: 186797/1 / MUESTREADA EL DÍA: 15/10/2009

Muestra	Uds	Ensayo	Descripción del material	Localización	Observaciones
3030	2	Mecasol - Compresion simple de probetas de suelo, UNE 103-400/1993	COLUMNAS DE SUPERJET GROUTING	SONDEO 1 - PROF 13.85-14.10 M	La probeta de ensayo tiene una relación a/d<2

```
DIMENSIONES DE LA PROBETA............... :
Altura.................................. :11.7 cm
Diámetro................................ :8.85 cm
Sección................................. :61.5 cm²
Volumen................................. :719.7 cm³
HUMEDAD................................. :
Humedad zona de rotura.................. :0.0 %
Humedad de la probeta................... :0.0 %
RESISTENCIA A COMPRESION CORREGIDA...... :
Carga................................... :799.20 Kp
Resistencia............................. :12.44 Kp/cm²
Deformación............................. :5.00 mm
DENSIDAD................................ :
Densidad Húmeda......................... :1.61 gr/cm³
Densidad Seca........................... :1.61 gr/cm³
```

RESULTADOS CORRESPONDIENTES A LA MUESTRA: 186797/2 / MUESTREADA EL DÍA: 15/10/2009

Muestra	Uds	Ensayo	Descripción del material	Localización	Observaciones
3040	2	Mecasol - Compresion simple de probetas de suelo, UNE 103-400/1993	COLUMNAS DE SUPERJET GROUTING	SONDEO 1 - PROF 16.40-16.70 M	La probeta de ensayo tiene una relación a/d<2

```
DIMENSIONES DE LA PROBETA............... :
Altura.................................. :12 cm
Diámetro................................ :7.3 cm
Sección................................. :41.9 cm²
Volumen................................. :502.2 cm³
HUMEDAD................................. :
Humedad zona de rotura.................. :0.0 %
Humedad de la probeta................... :0.0 %
RESISTENCIA A COMPRESION CORREGIDA...... :
Carga................................... :299.40 Kp
Resistencia............................. :5.88 Kp/cm²
Deformación............................. :3.71 mm
DENSIDAD................................ :
Densidad Húmeda......................... :1.70 gr/cm³
Densidad Seca........................... :1.70 gr/cm³
```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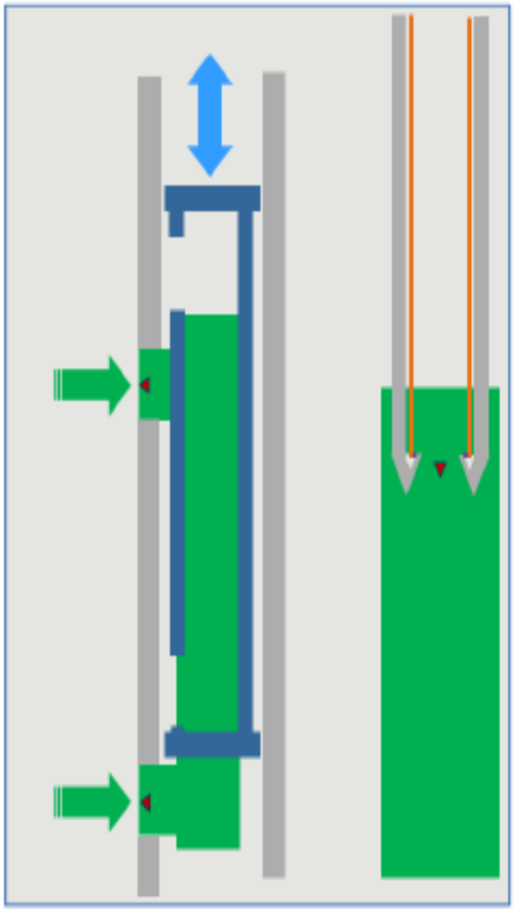
IMPROVED SOIL CHARACTERISTICS

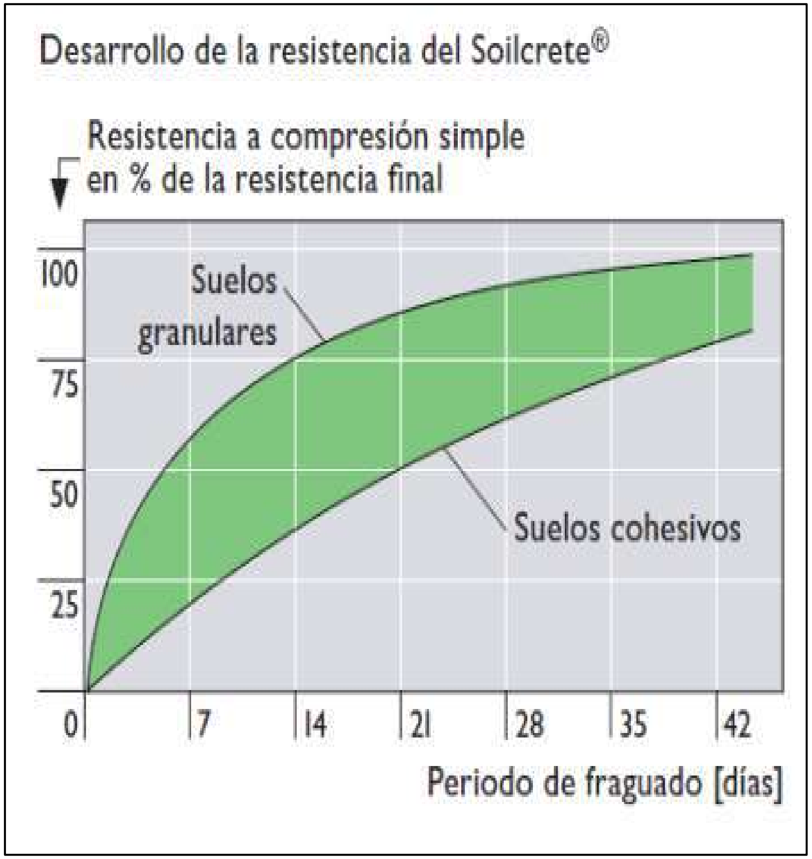


– Wet samples (fresh jet grouting)

	Profundidad (m)	Muestras	Resistencia Tracción (MPa)	Días desde la toma de muestra	RCS 3 días (MPa)	RCS 7 días (MPa)	Densidad Lechada (t/m^3)
P1	15,00	M18-1	1,53	7,00		4,66	1,55-1,57
	15,00	M18-3	1,48	3,00	4,45		
	15,00	M19-1	1,53	3,00	4,20		
	15,00	M19-3	1,39	7,00		3,88	
P2	18,00	M26-1	1,53	3,00	5,69		1,55-1,57
	18,00	M26-3	1,39	7,00		4,01	
	18,00	M27-1	1,60	3,00	5,80		
	18,00	M27-3	1,67	7,00		5,81	
	15,00	M28-1	1,64	4,00	4,64		
	15,00	M28-2	1,69	7,00		5,06	
	15,00	M29-1	1,69	7,00		5,18	
P3	15,00	M1-1	0,9	7,00		4,6	1,52-1,55
	15,00	M1-3	0,9	7,00		4,5	
	15,00	M3-1	0,7	4,00	3,90		
	15,00	M3-2	0,8	7,00		4,1	
	18,00	M5-1	0,9	7,00		4,3	
	18,00	M5-2	0,9	4,00	3,10		
	18,00	M5-3	0,7	7,00		3,2	

IMPROVED SOIL CHARACTERISTICS

– Wet samples (fresh jet grouting)



	Profundidad (m)	Muestras	Resistencia Tracción (MPa)	Días desde la toma de muestra	RCS 3 días (MPa)	RCS 7 días (MPa)	Densidad Lechada (t/m³)
P1	15,00	M18-1	1,53	7,00		4,66	1,55-1,57
	15,00	M18-3	1,48	3,00	4,45		
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	18,00	M27-3	1,67	7,00		5,81	
	15,00	M28-1	1,64	4,00	4,64		
	15,00	M28-2	1,69	7,00		5,06	
	15,00	M29-1	1,69	7,00		5,18	
P3	15,00	M1-1	0,9	7,00		4,6	1,52-1,55
	15,00	M1-3	0,9	7,00		4,5	
	15,00	M3-1	0,7	4,00	3,90		
	15,00	M3-2	0,8	7,00		4,1	
	18,00	M5-1	0,9	7,00		4,3	
	18,00	M5-2	0,9	4,00	3,10		
	18,00	M5-3	0,7	7,00		3,2	

IMPROVED SOIL CHARACTERISTICS

- Technical specifications:
  - UCS: 3,50 Mpa
  - C ≥ 0,50 Mpa
  - E = 1.800 – 4.000 Mpa
  - Density ≥ 19 kN/m^3

- Wet samples (fresh jet grouting)
- Core drilling (aprox. 28 days)

CONFIRMED

COLUMNAS ENSAYADAS	SONDEO	PROFUNDIDAD m	DENSIDAD t/m²	CARGA KP	RESISTENCIA CORREGIDA MPa
C2-C4	S-1	11	1,63	6054,08	5,19
C2-C4	S-1	13	1,83	14506,12	12,56
C2-C4	S-1	17	1,71	3651,02	3,16
C3-C5-C6	S-3	17	1,71	4178,57	3,65
C3-C5-C6	S-3	11	1,71	5124,49	4,44
C3-C5-C6	S-3	13	1,75	4936,73	4,27
C2-C3	S-2	13	1,80	4367,35	3,78
C2-C3	S-2	17	1,95	12320,41	10,56
C2-C3	S-2	11	1,83	3672,45	3,21

Tabla 5 Resumen de los resultados obtenidos en las muestras extraidas en los sondeos.

IMPROVED SOIL CHARACTERISTICS

- Lugeon permeability tests:

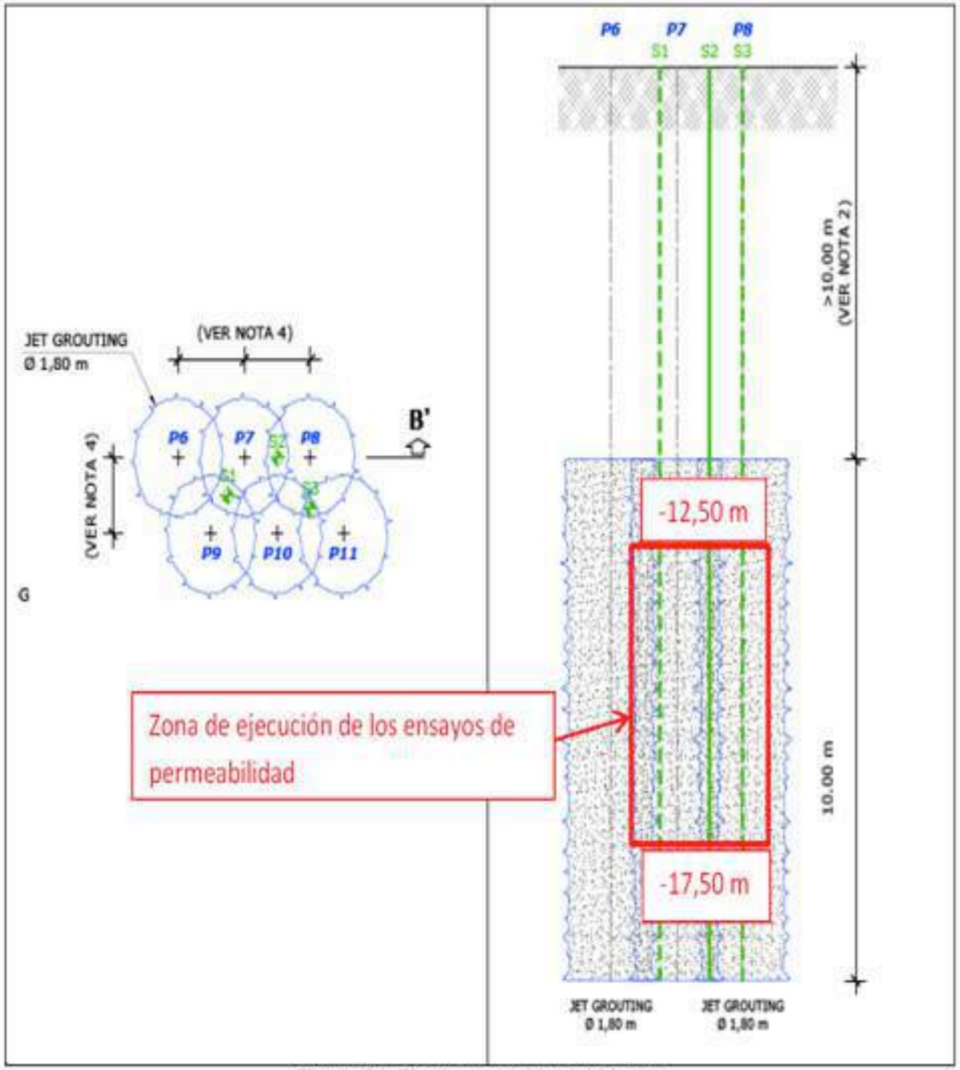

Figura 24. Planta y sección del bloque

IMPROVED SOIL CHARACTERISTICS

- Lugeon permeability tests:
  - Max. pressure: 4 bars
  - Factor safety > 1,3
  - 10 min pressure phases
  - Med. perm.:9,5·10^{-8} m/seg

PUNTO DE ENSAYO	SONDEO	PERMEABILIDAD MEDIDA (m/s)
C2-C4	S-1	1,34 x 10^{-7}
C2-C3	S-2	9,62 x 10^{-8}
C3-C5-C6	S-3	5,71 x 10^{-8}

Tabla 7 Resumen de las permeabilidades medida

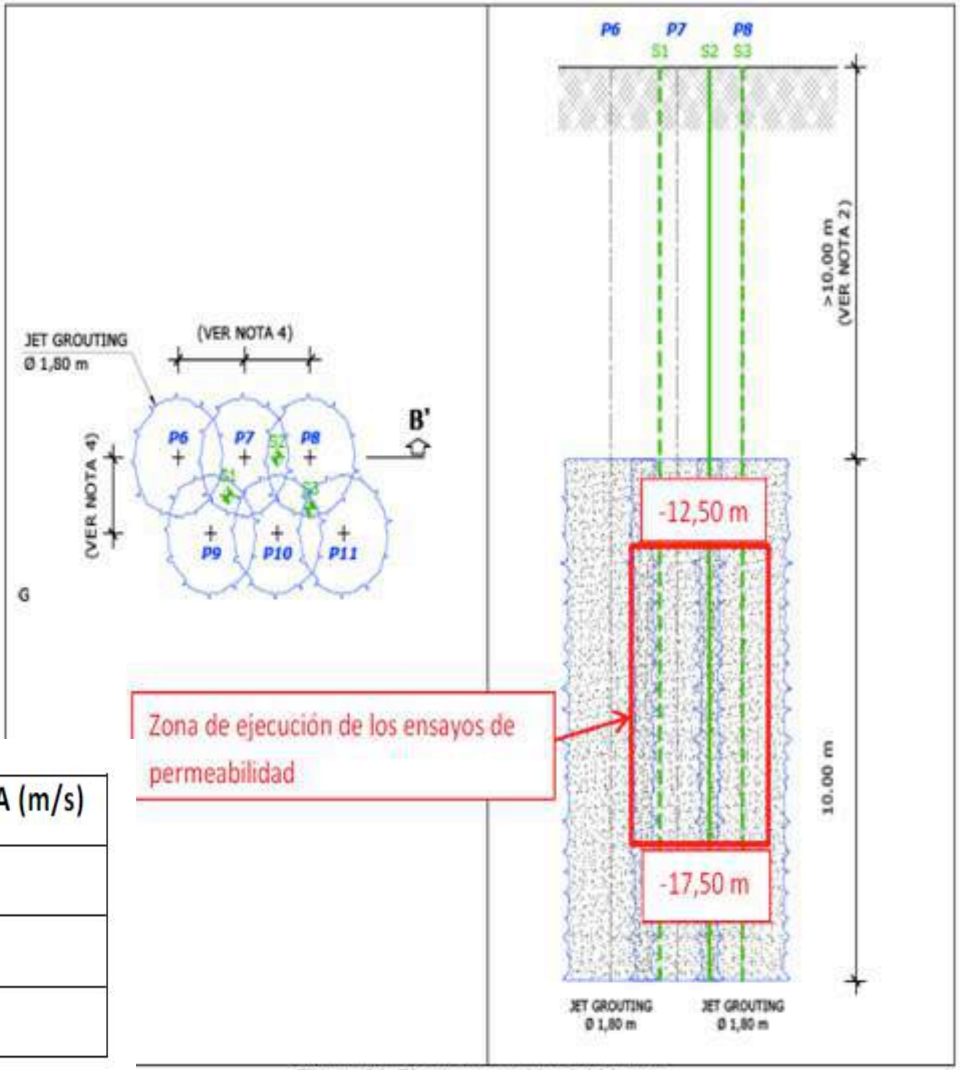

Figura 24. Planta y sección del bloque

EXECUTION PARAMETERS

- Different types of monitors and nozzles (DX, D, DS)
- Nozzle: 2 x 4.6 mm / 6,5 mm
- Pressure: 400-600 bares
- Grout density: 1.5-1.55 t/m^3
- Flow rate: 420-650 l/min

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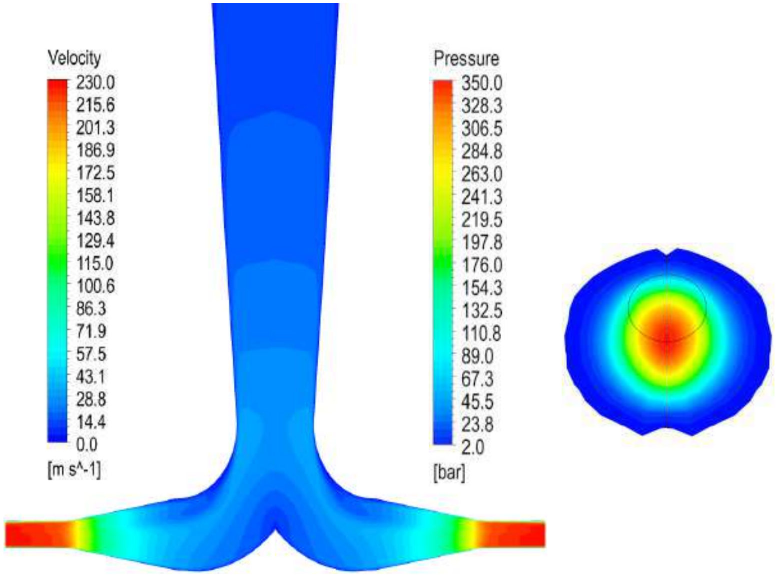
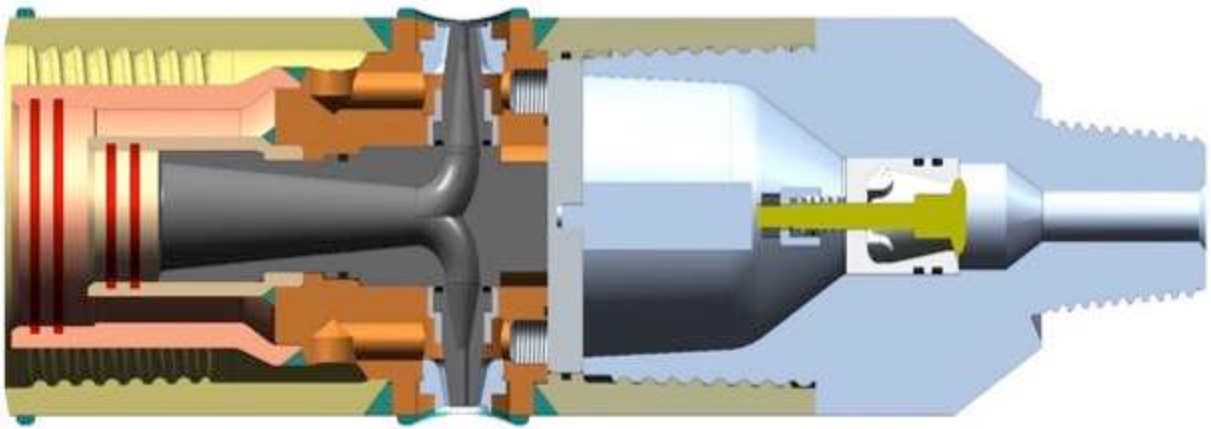
EXECUTION PARAMETERS

- Different types of monitors and nozzles (DX, D, DS)
- Nozzle: 2 x 4.6 mm / 6,5 mm
- Pressure: 400-500 bares
- Grout density: 1.5-1.55 t/m^3
- Flow rate: 420-650 l/min





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- Pressure: 400-500 bares
- Grout density: 1.5-1.55 t/m^3
- Flow rate: 420-650 l/min

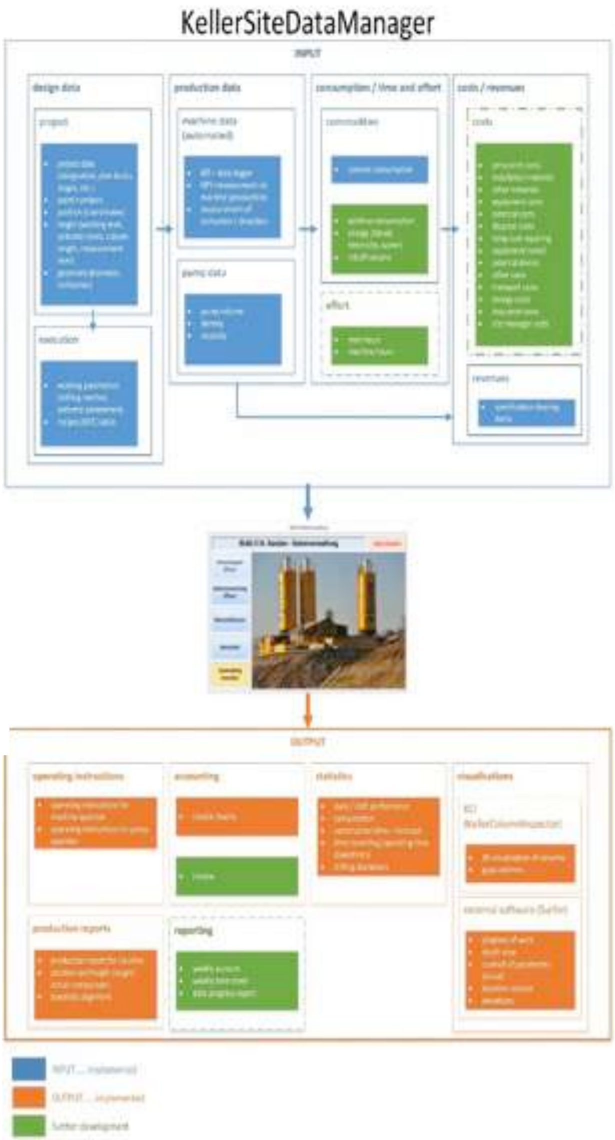
Trial	Monitor	Nozzle	DN [mm]	average equivalent force [kN]	area [cm²]	stress F/A [kN/cm²]
1	Japan asymmetrisch	Japan	4,60	0,883	10,20	0,087
2	Japan asymmetrisch	Japan abgesetzt	4,60	0,838	11,20	0,075
3	Japan asymmetrisch	Japan	6,00	1,525	19,03	0,080
4	Keller Standard 114mm	Japan	4,60	0,890	18,70	0,048
5	Keller Standard 114mm	Japan abgesetzt	4,60	0,842	24,98	0,034
6	Keller Standard 114mm	Japan	6,00	1,523	29,49	0,052
8	Keller Standard 114mm	Keller DS	6,00	1,417	34,58	0,041
13	Keller DX	Keller DS	6,00	1,857	41,37	0,045

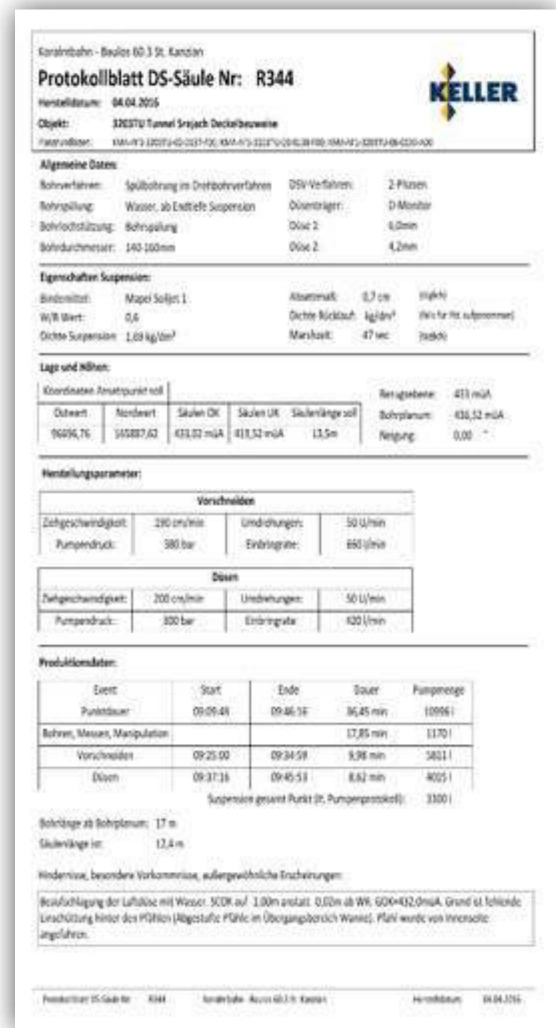
EXECUTION PARAMETERS

- Different types of monitors and nozzles (DX, D, DS)
- Nozzle: 2 x 4.6 mm / 6,5 mm
- Pressure: 400-500 bares
- Grout density: 1.5-1.55 t/m^3
- Flow rate: 420-650 l/min

KELLER SITE DATA MANAGER

- Flowchart





Koralmbahn - Baulos 60.3 St. Kanzian

Protokollblatt DS-Säule Nr: R344

Herstelldatum: 04.04.2016

Objekt: 3203TU Tunnel Srejach Deckelbauweise

Allgemeine Daten:

Bohrverfahren:	Spülbohrung im Drehbohrverfahren	DSV-Verfahren:	2-Phasen
Bohrspülung:	Wasser, ab Endtiefe Suspension	Düsenträger:	D-Monitor
Bohrlochstützung:	Bohrspülung	Düse 1:	6,0mm
Bohrdurchmesser:	140-160mm	Düse 2:	4,2mm

Eigenschaften Suspension:

Bindemittel:	Mapei Soiljet 1	Absetzmaß:	0,7 cm
W/B Wert:	0,6	Dichte Rücklauf:	kg/dm³
Dichte Suspension:	1,69 kg/dm³	Marshzeit:	47 sec

Lage und Höhen:

Koordinaten Ansatzpunkt soll				
Ostwert	Nordwert	Säulen OK	Säulen UK	Säulenlänge soll
96696,76	165887,62	431,02 müA	418,52 müA	13,5m

Bezugsebene: 433 müA
Bohrplanum: 430,52 müA
Neigung: 0,00 °

Herstellungsparameter:

Vorschneiden			
Ziehgeschwindigkeit:	190 cm/min	Umdrehungen:	50 U/min
Pumpendruck:	380 bar	Einbringrate:	660 l/min

Düsen			
Ziehgeschwindigkeit:	200 cm/min	Umdrehungen:	50 U/min
Pumpendruck:	300 bar	Einbringrate:	420 l/min

Produktionsdaten:

Event	Start	Ende	Dauer	Pumpmenge
Punktdauer	09:09:48	09:46:16	36,45 min	10996 l
Bohren, Messen, Manipulation			17,85 min	1170 l
Vorschneiden	09:25:00	09:34:59	9,98 min	5821 l
Düsen	09:37:16	09:45:53	8,62 min	4005 l
			Suspension gesamt Punkt (lt. Pumpenprotokoll):	3300 l

Bohrlänge ab Bohrplanum: 17 m
Säulenlänge ist: 12,4 m

Hindernisse, besondere Vorkommnisse, außergewöhnliche Erscheinungen:

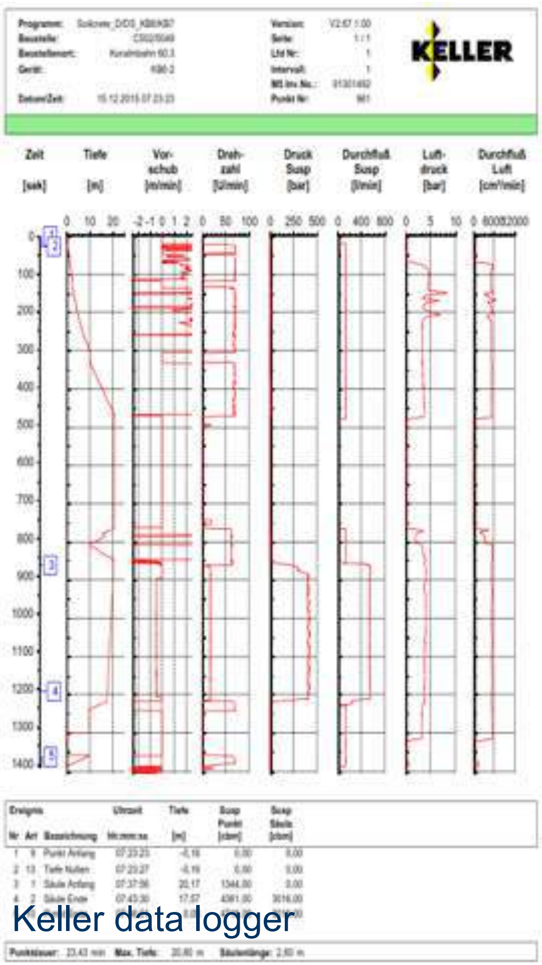
Beaufschlagung der Luftdüse mit Wasser. SOK auf 1,00m anstatt 0,02m ab WK. GOK=432,0müA. Grund ist fehlende Leitschützung hinter den Pfählen (Abgestufte Pfähle im Übergangsbereich Wanne). Pfahl wurde von Innenseite angefahren.

Herstelldatum: 04.04.2016

KELLER

KELLER SITE DATA MANAGER

- Documentation for each column



Keller data logger


Koralmbahn - Baulos 60.3 St. Kanzian

Protokollblatt DS-Säule Nr: 961

KELLER

Herstelldatum: 15.12.2015

Objekt: 3203TU Tunnel Srejach Deckelbauweise

Planunterlagen:

Allgemeine Daten:

Bohrverfahren:	Spülbohrung im Drehbohrverfahren	DSV-Verfahren:	2-Phasen
Bohrspülung:	Wasser, ab Endtiefe Suspension	Düsenträger:	DK-Monitor
Bohrlochstützung:	Bohrspühlung	Düse 1:	6,0mm
Bohrdurchmesser:	140-160mm	Düse 2:	4,2mm

Eigenschaften Suspension:

Bindemittel:	Mapei Soiljet 1	Absetzmaß:	2,5 cm
W/B Wert:	1,0	Dichte Rücklauf:	kg/dm³
Dichte Suspension:	1,52 kg/dm³	Marshzeit:	38 sec

Lage und Höhen:

Koordinaten Ansatzpunkt soll				
Ostwert	Nordwert	Säulen OK	Säulen UK	Säulenlänge soll
97061,72	165794,29	423,43 müA	420,83 müA	2,6m

Bezugsebene: 441 müA
Bohrplanum: 439,92 müA
Neigung: 0,00 °

Herstellungsparameter:

Vorschneiden			
Ziehgeschwindigkeit:	0 cm/min	Umdrehungen:	0 U/min
Pumpendruck:	0 bar	Einbringrate:	0 l/min

Düsen			
Ziehgeschwindigkeit:	50 cm/min	Umdrehungen:	17 U/min
Pumpendruck:	400 bar	Einbringrate:	510 l/min

Produktionsdaten:

Event	Start	Ende	Dauer	Pumpmenge
Punktdauer	07:23:23	07:46:51	23,47 min	4716 l
Bohren, Messen, Manipulation			17,9 min	1700 l
Vorschneiden				
Düsen	07:37:56	07:43:30	5,57 min	3016 l

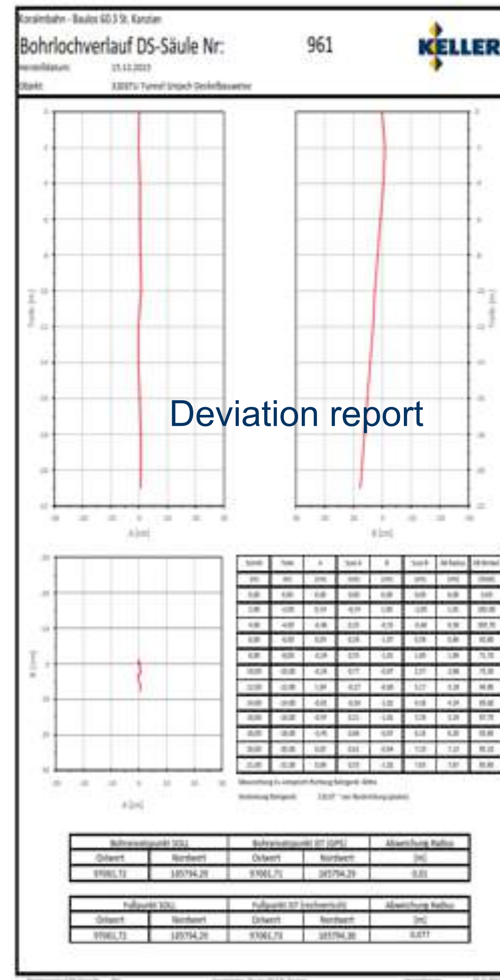
Suspension gesamt Punkt (lt. Pumpenprotokoll): 3100 l

Bohrlänge ab Bohrplanum: 19,09 m
Säulenlänge ist: 2,6 m

Hindernisse, besondere Vorkommnisse, außergewöhnliche Erscheinungen:

keine

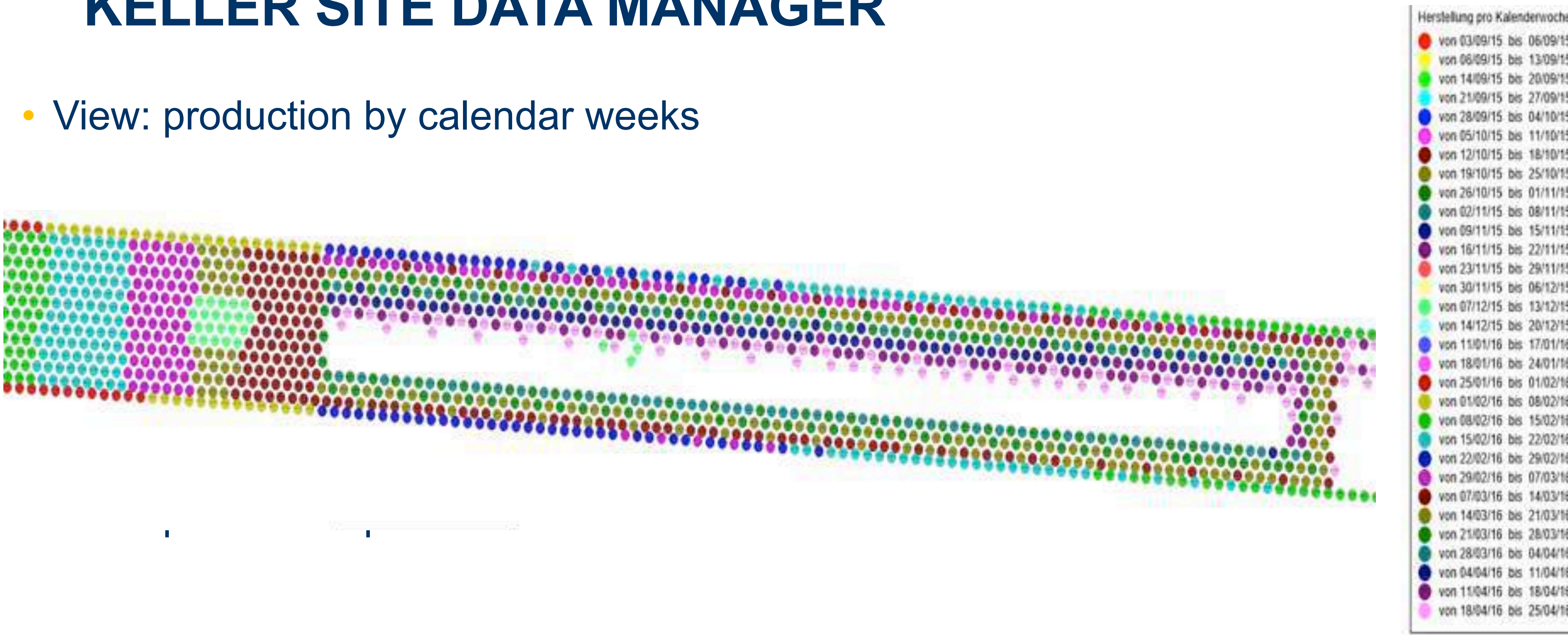
Summary report

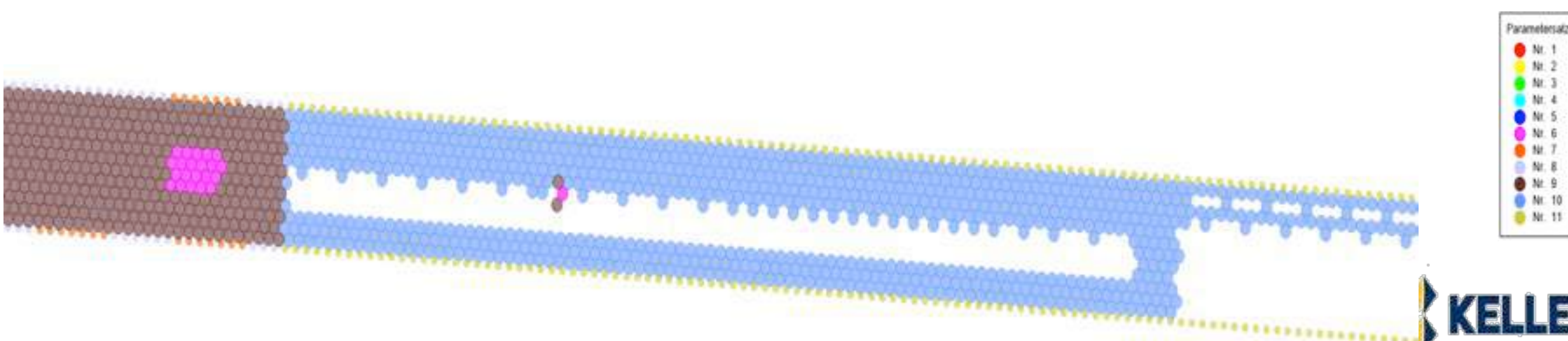


Deviation report

KELLER SITE DATA MANAGER

- View: production by calendar weeks





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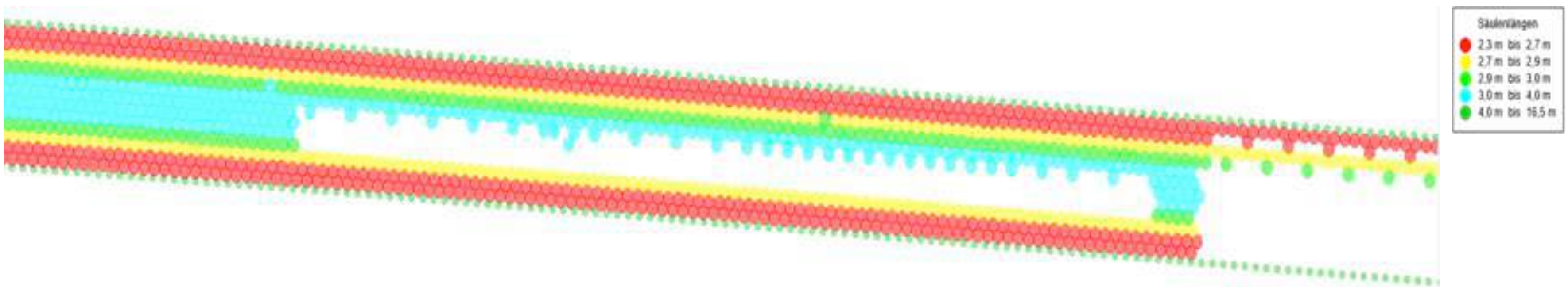
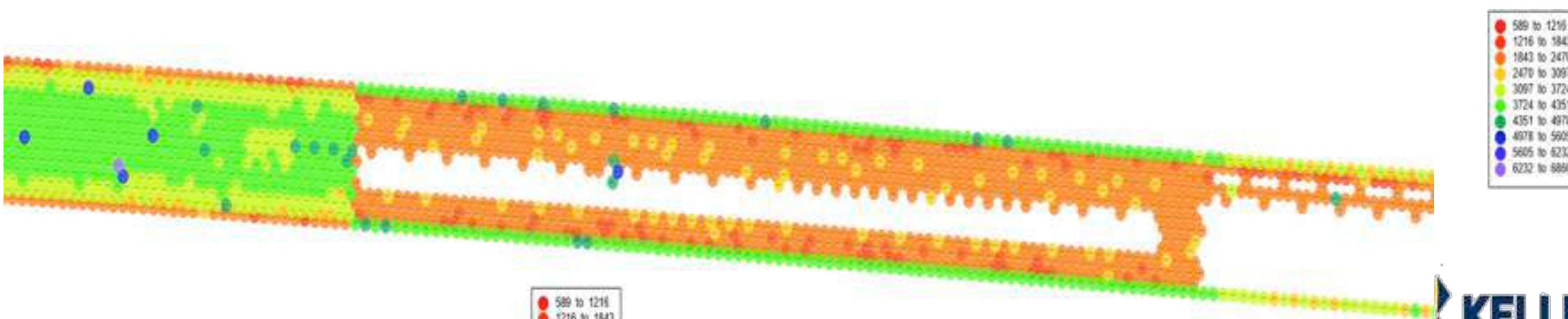
KELLER SITE DATA MANAGER

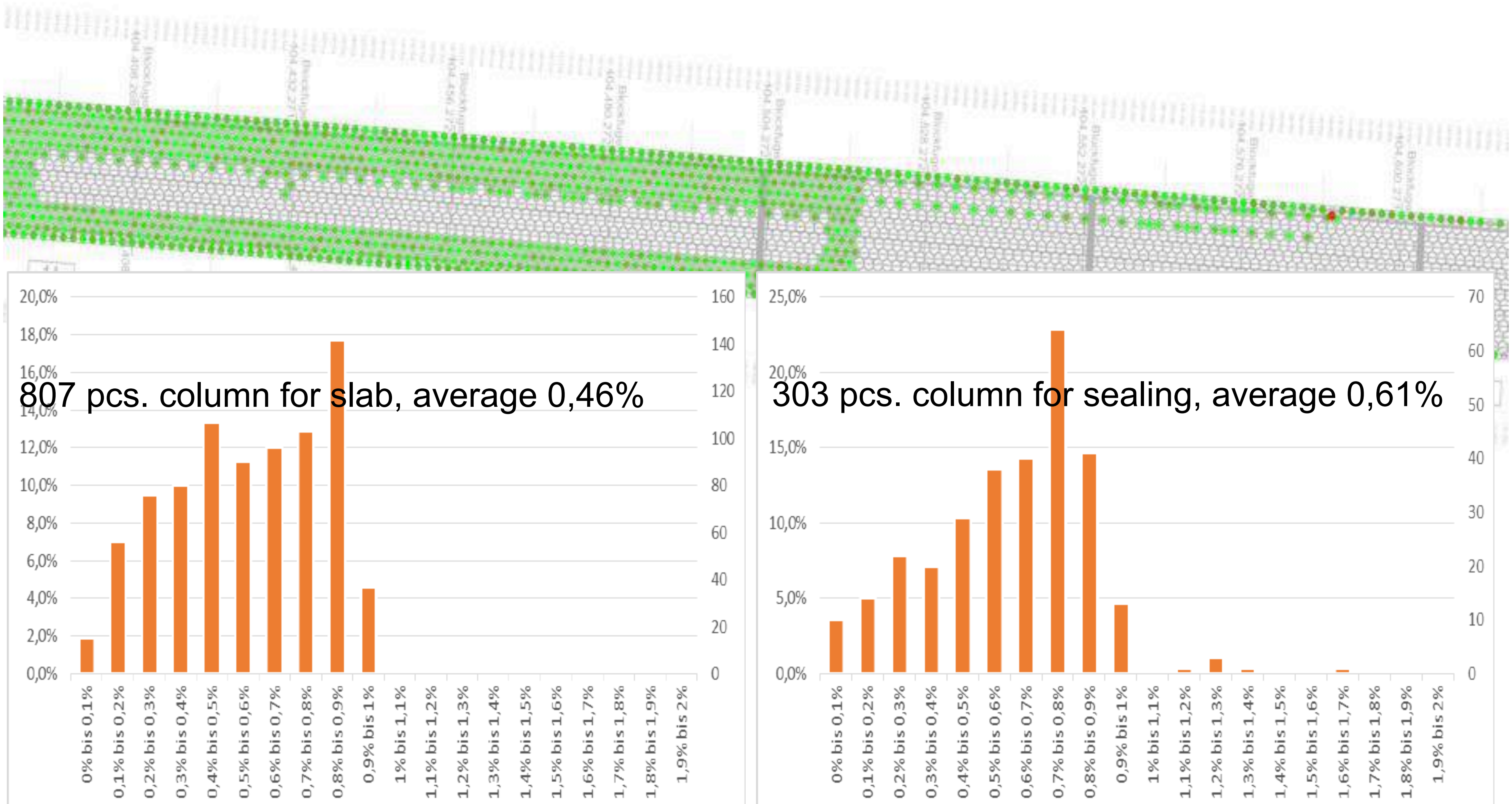
- View: column length





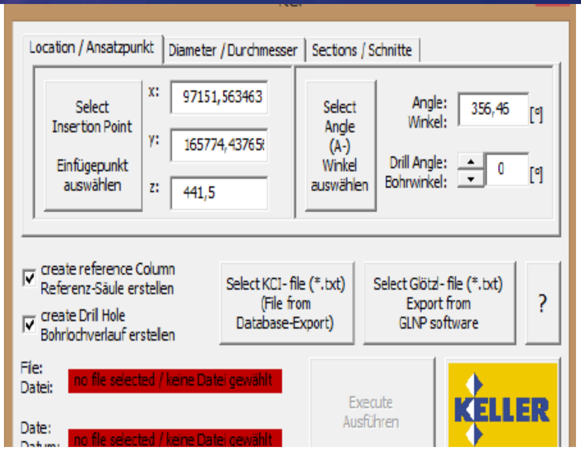
KELLER SITE DATA MANAGER

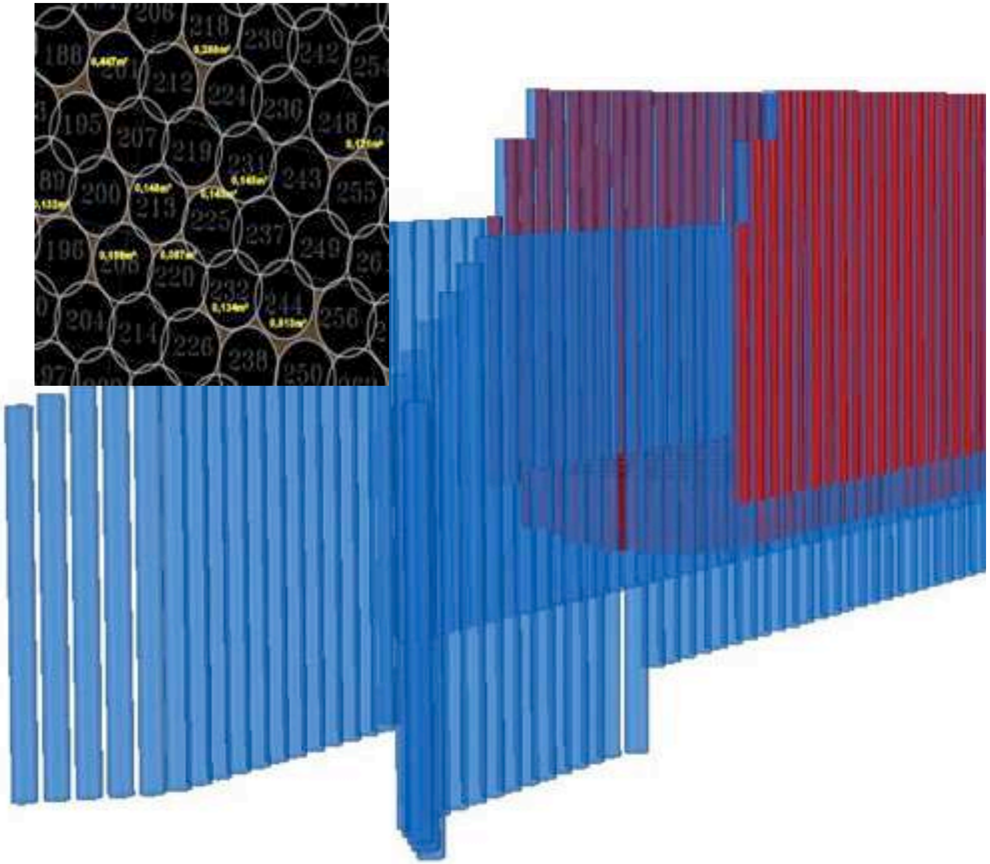
- View: deviation

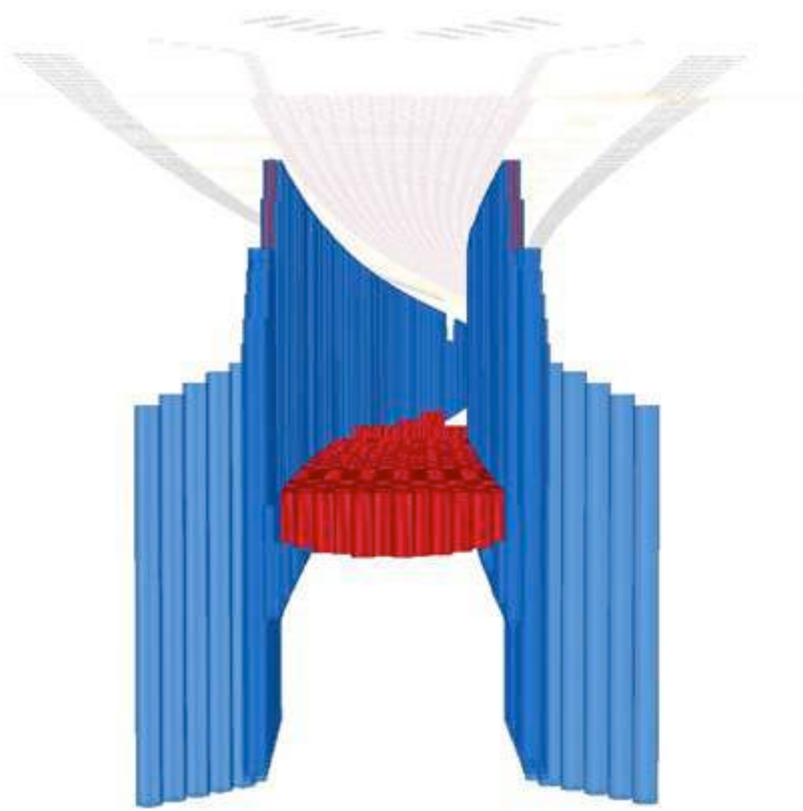


KELLER SITE DATA MANAGER

- KCI: real 3D
  - select KCI - exportfile from KSDM







EQUIPMENT AND EXECUTION

- 4 rigs
- double shift, 6 days per week
- 8 teams

- Total drilling length: 293.400 m
- Total jetting length: 85.000 m

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EQUIPMENT AND EXECUTION

- New generation jet grouting rigs:

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EQUIPMENT AND EXECUTION

- New generation jet grouting rigs:

KELLER

EQUIPMENT AND EXECUTION

- New generation jet grouting rigs:

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EQUIPMENT AND EXECUTION

- New generation jet grouting rigs:

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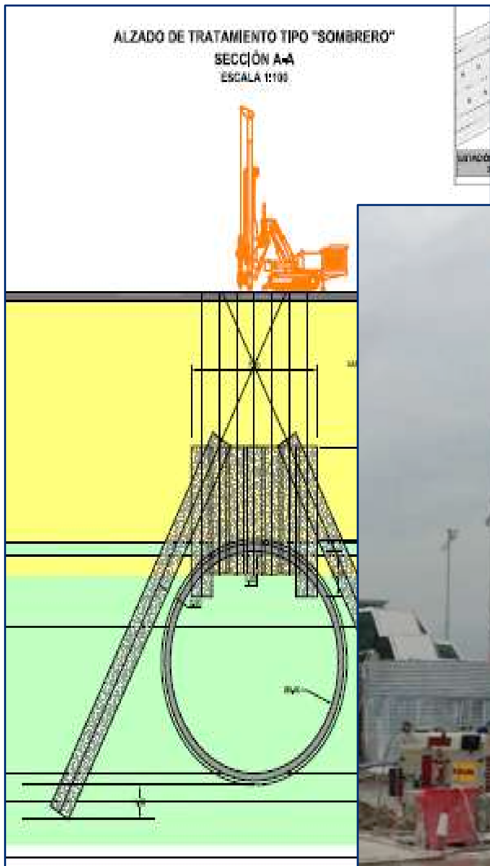
EQUIPMENT AND EXECUTION

- Special jet grouting rigs for inclined columns:



EQUIPMENT AND EXECUTION

- New generation jet grouting pumps and plants:
  - Pressure up to 900 bars
  - Flow rate > 800 lit/min

EQUIPMENT AND EXECUTION

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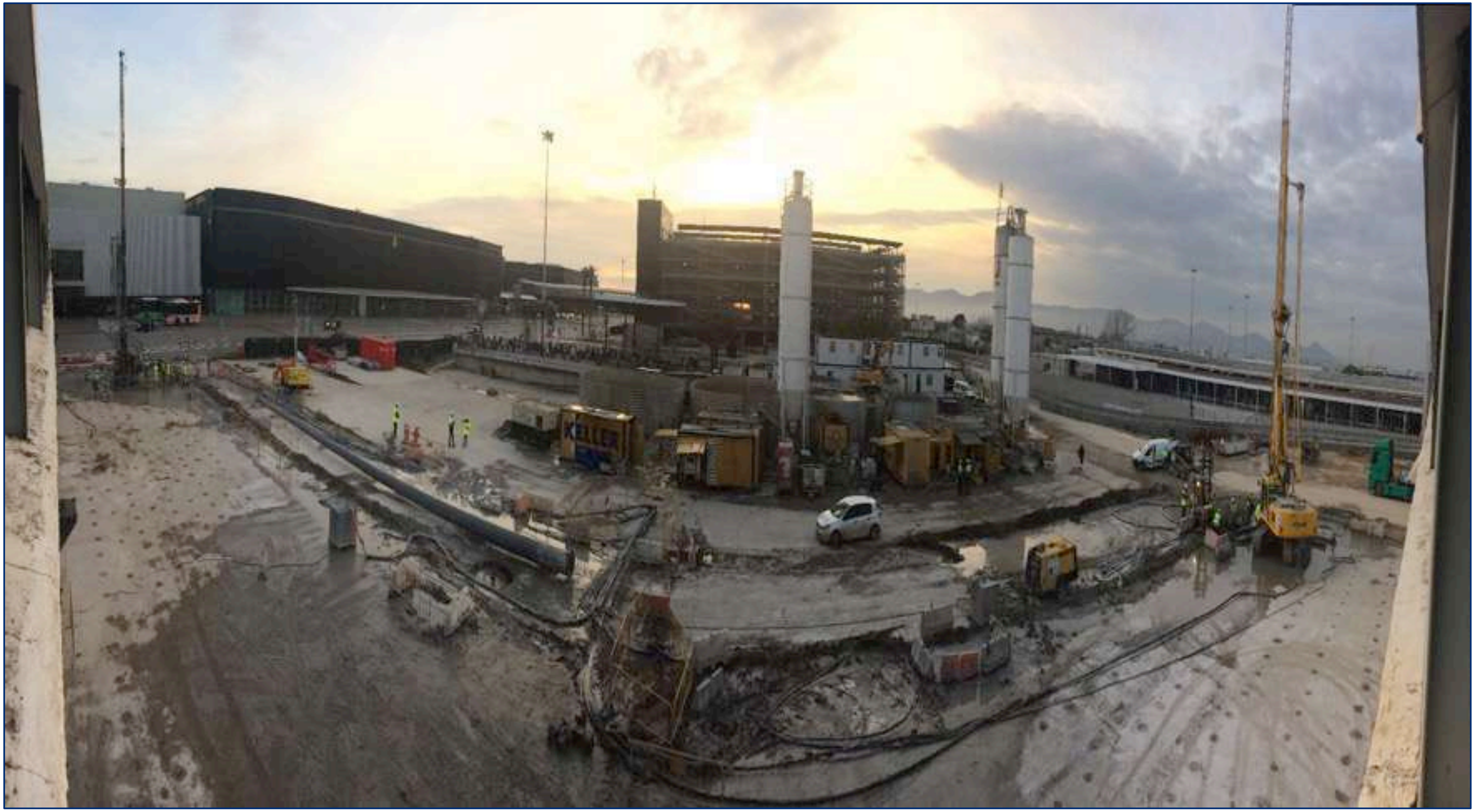
EQUIPMENT AND EXECUTION

KELLER

EQUIPMENT AND EXECUTION



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EQUIPMENT AND EXECUTION

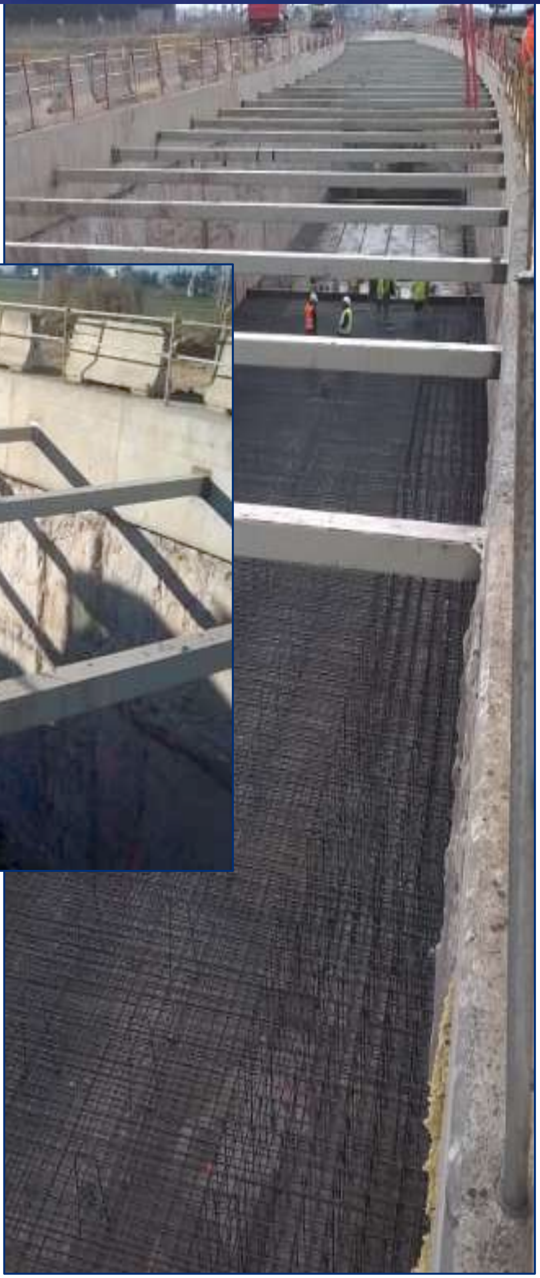
KELLER

EQUIPMENT AND EXECUTION

KELLER

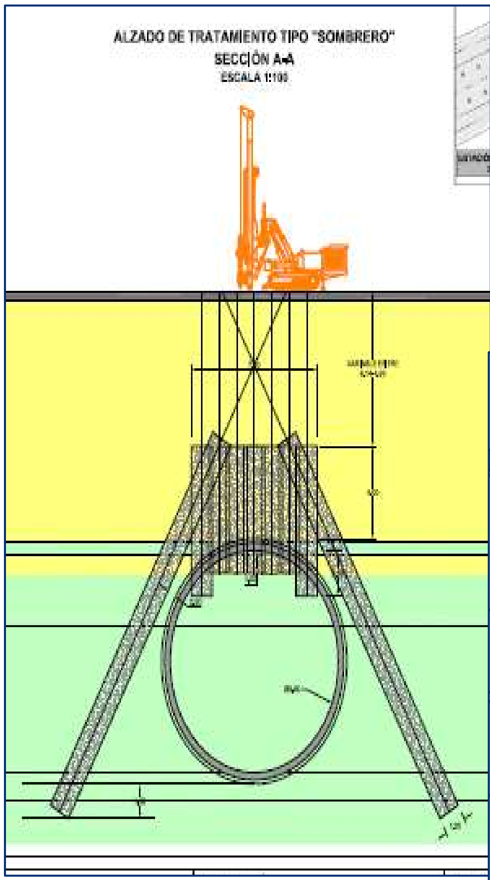
EQUIPMENT AND EXECUTION

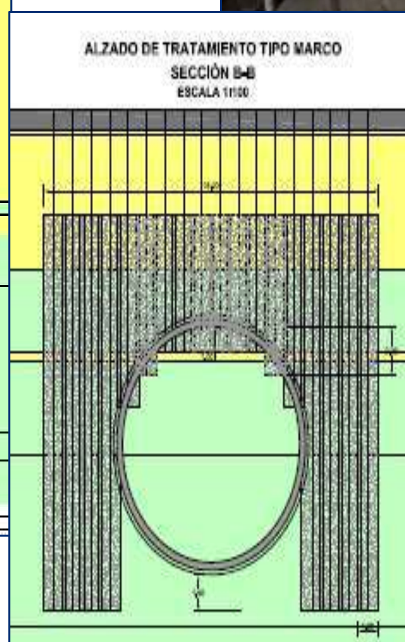
- Already finished:

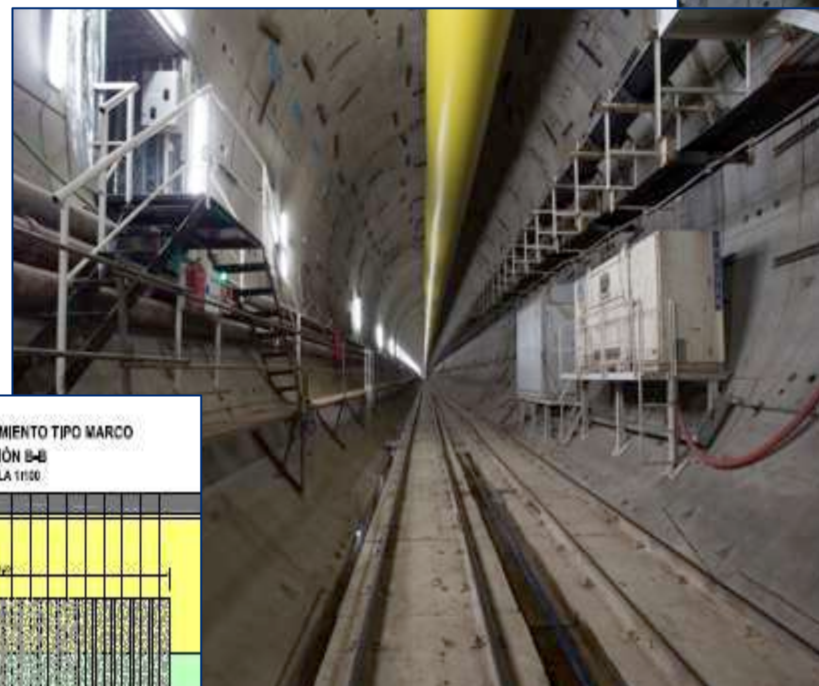


EQUIPMENT AND EXECUTION

- Already finished:







- SUMMARY:

- SUMMARY:
  - JET GROUTING
    - Its versatility and flexibility together with its field of applications, in almost every soil formation, makes it a perfect solution for complex geotechnical problems.
    - It is effective in open field as well as in confined space with limited headroom, since the column diameter does not correspond to the size of the rig.
    - In the last decade, the unique features of this technology were used in almost all high profile transportation and infrastructure projects in Europe in order to facilitate the construction process and to improve the level of safety and efficiency.
    - Application of the recent technology was presented.

- SUMMARY:
  - JET GROUTING
    - Importance of QAQC and trial field tests:
      - Diameter control: ACI
      - Importance of verticality; design consideration and control; IncliJet
      - Geomechanical characteristics control
    - New generation equipment
      - New rigs (mast > 40 m)
      - High capacity pumps and plants (> 500 bars and flow rate > 600 l/min)
      - New nozzle, rods and monitor design – better efficiency

Soil improvement by jet grouting for the construction of the Access to the Barcelona Airport
Application of the recent technologies

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Goran Vukotić

Keller

MUITO OBRIGADO PELA VOSSA ATENÇÃO!

Organização

Sociedade Portuguesa de Geotecnia

CPGT
Comissão Portuguesa de Geotecnia nos Transportes

igs Portugal
Comissão Portuguesa de Geossintéticos

Câmara Municipal de Vila Franca de Xira
www.cm-vfxira.pt

Apoios

LNEC LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

ORDEM DOS ENGENHEIROS

Successful Menard Vacuum trial area in the New Mexico City Airport

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TC211 Vice-Chairman

Engineering Director

menard

Organização

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Câmara Municipal

Apoios

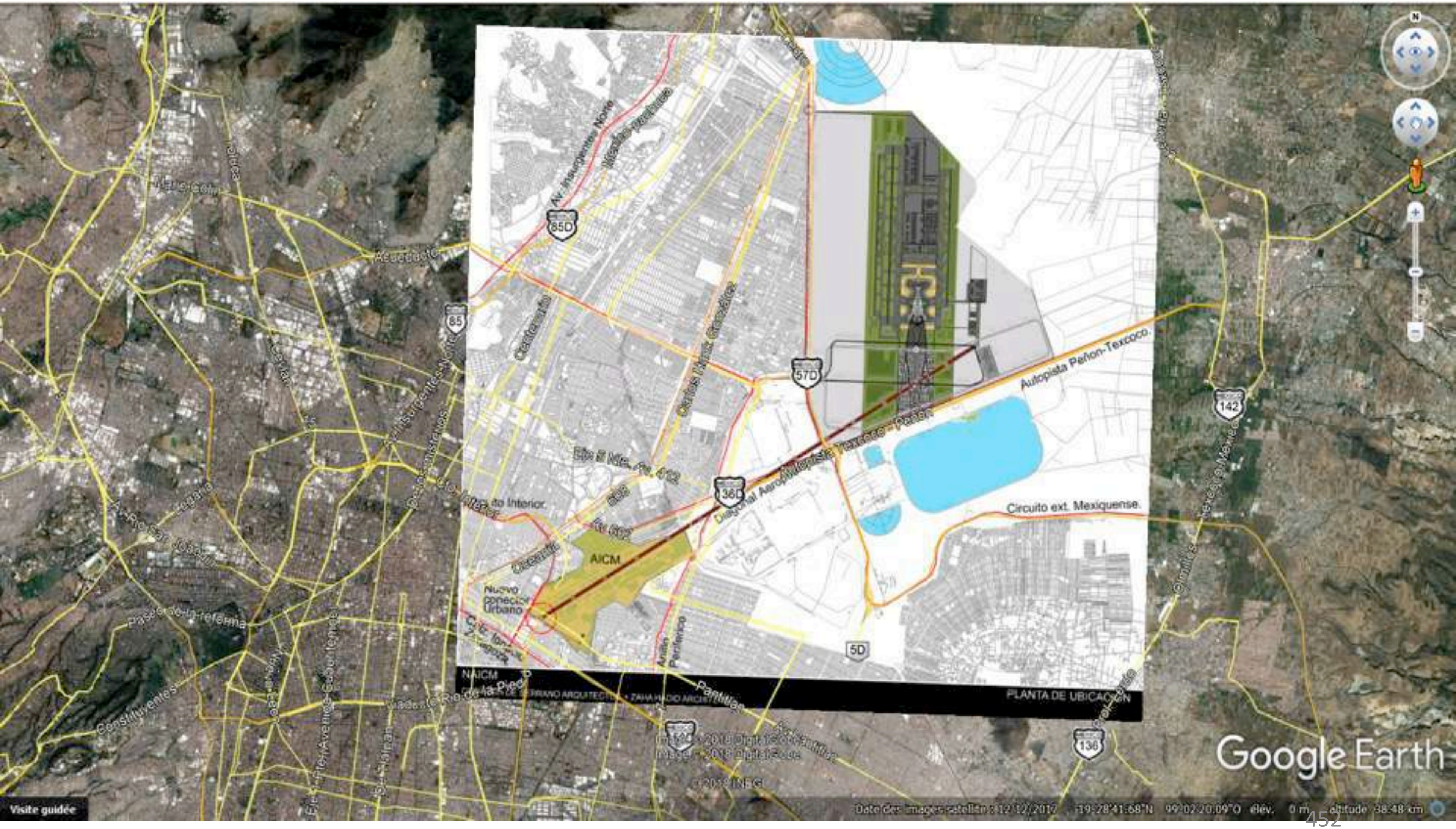
LNEC Laboratório Nacional de Engenharia Civil

Ordem dos Engenheiros

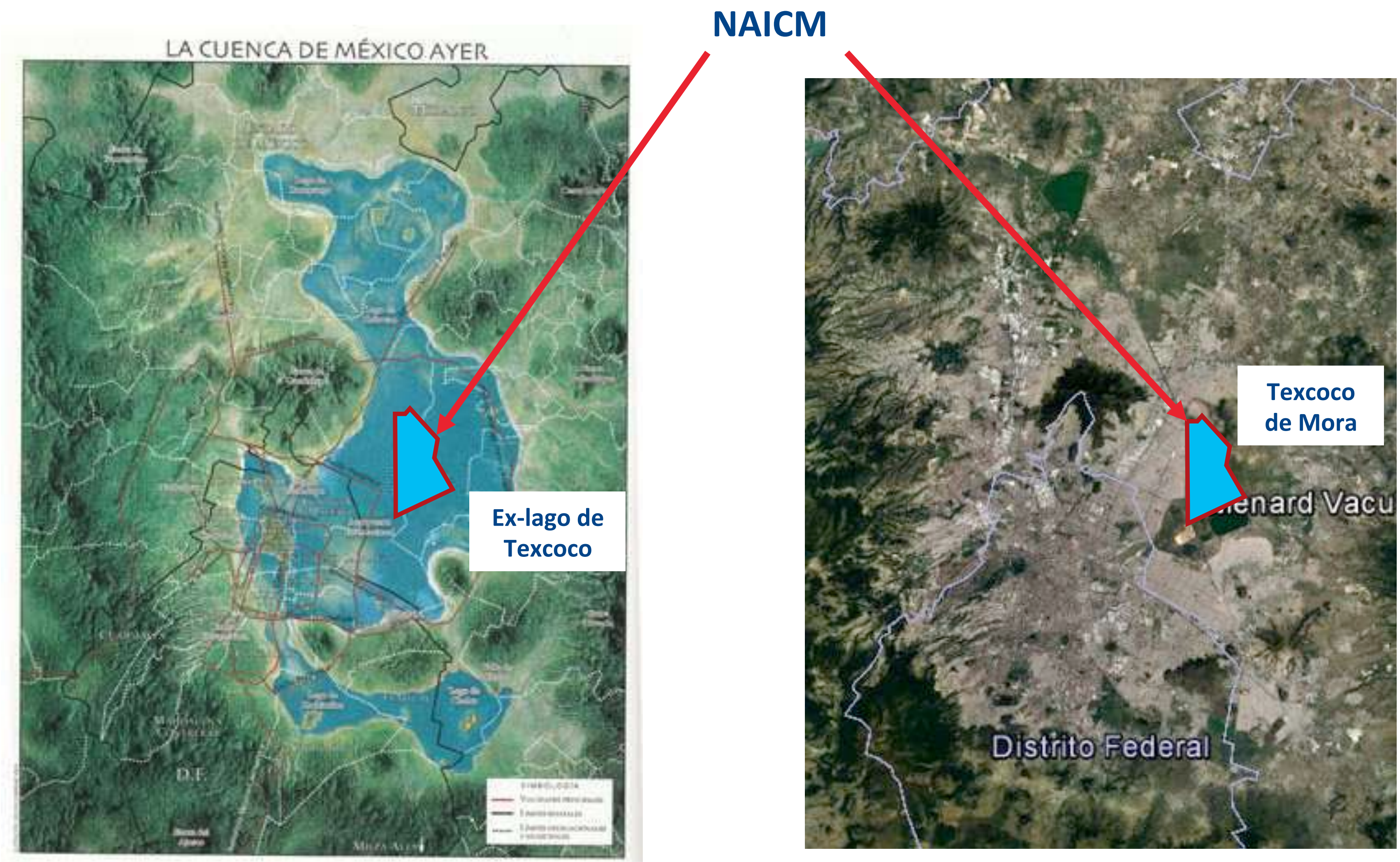
The New Mexico City International Airport (NAICM)

1st phase in operation: October 2020
Total area: 4 430 hectares
X-shaped terminal: 743,000 m^2
Runways: 3
Passengers per year: 68 millions

Soil conditions



Soil conditions



Soil conditions

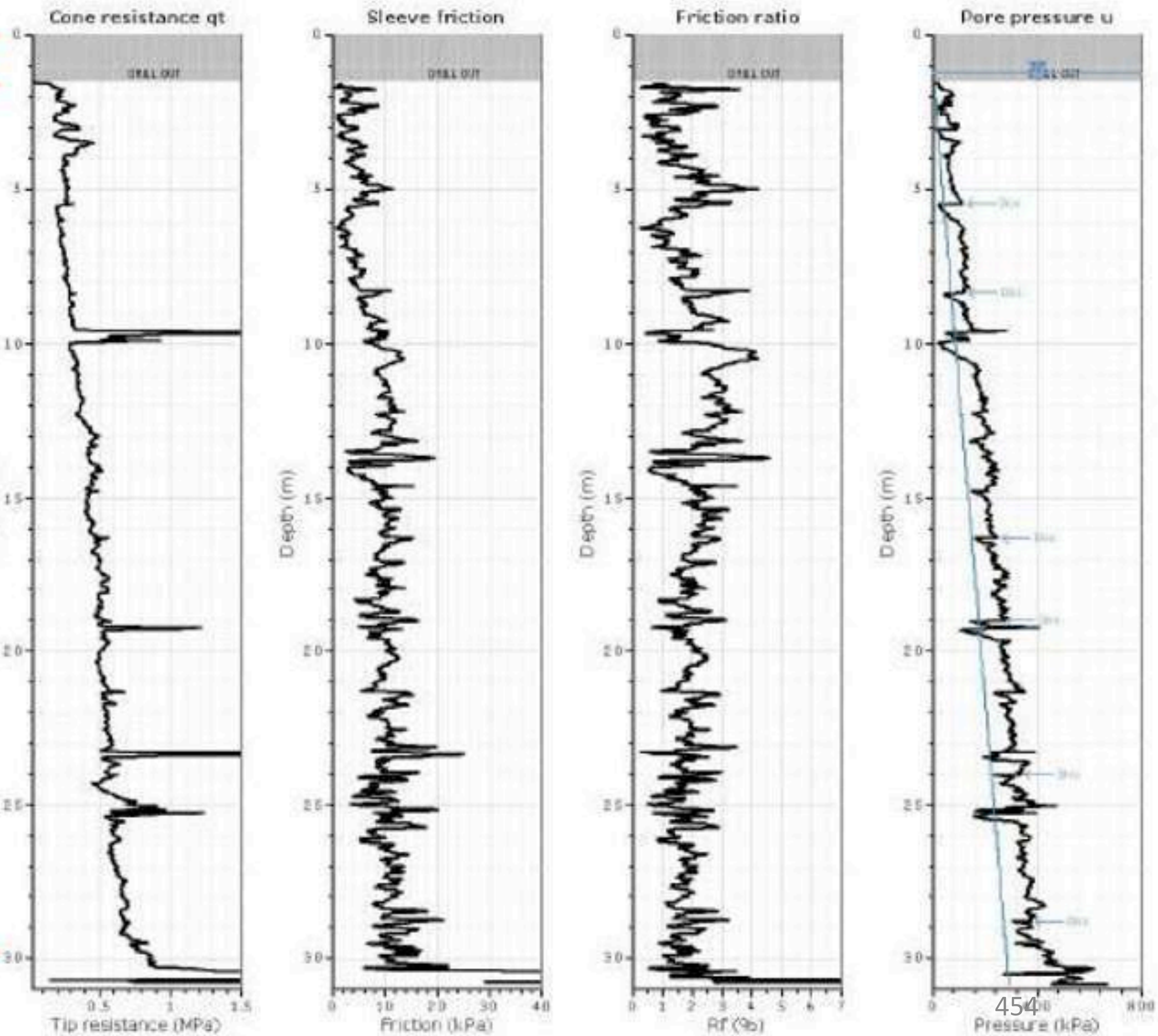
Plataforma de Tezontle

NAF ~ 1.10 m

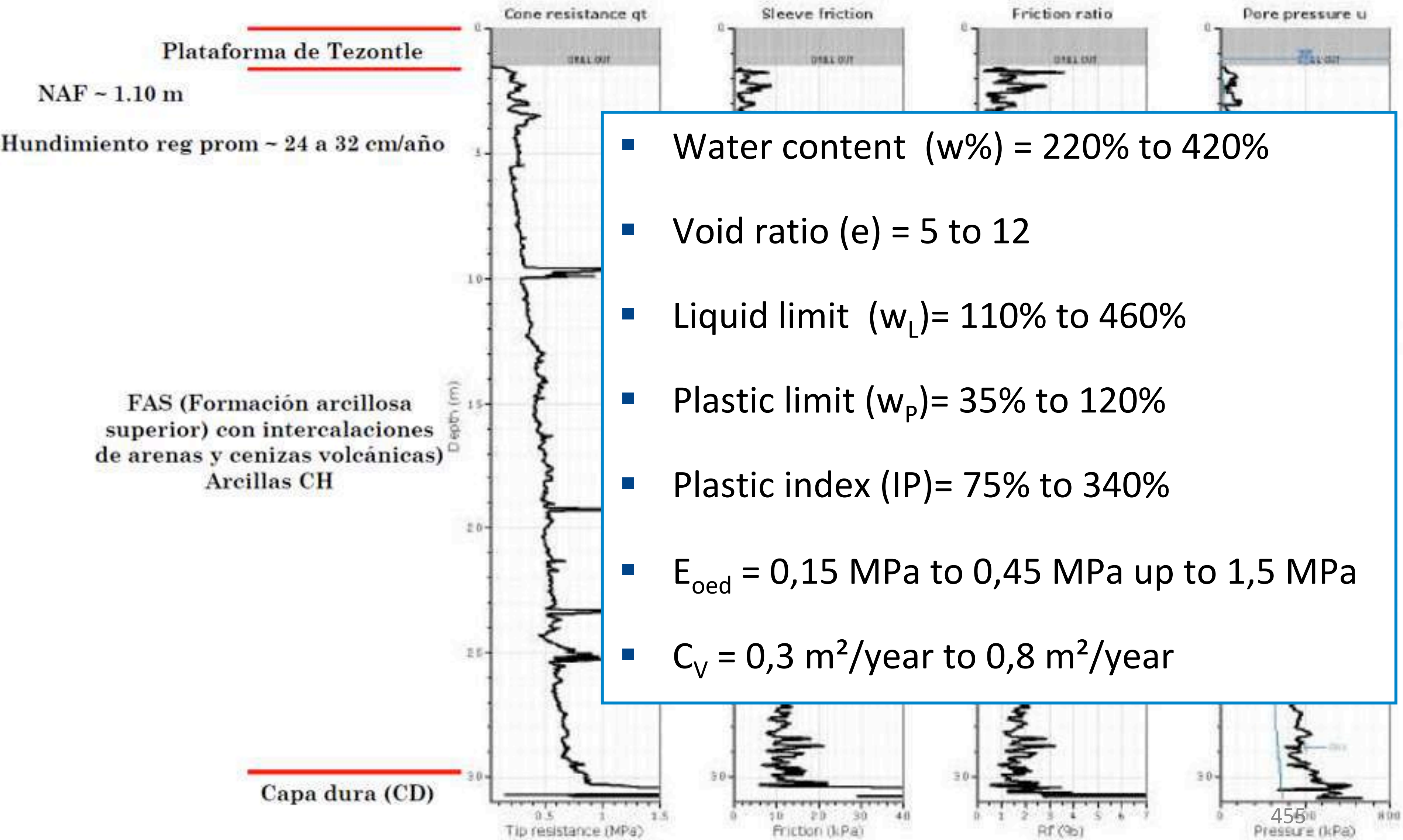
Hundimiento reg prom ~ 24 a 32 cm/año

FAS (Formación arcillosa superior) con intercalaciones de arenas y cenizas volcánicas) Arcillas CH

Capa dura (CD)



Soil conditions



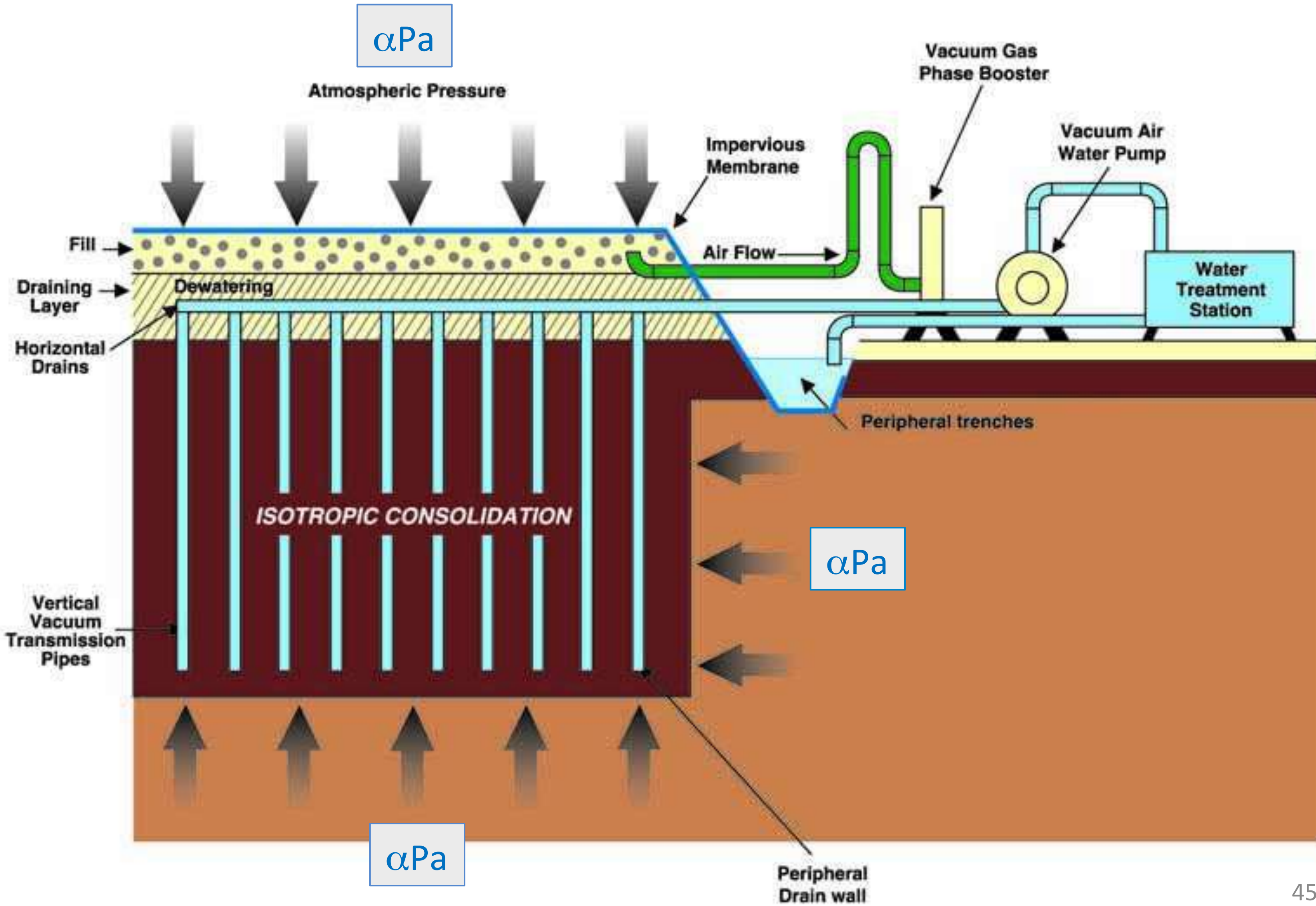
- Water content (w%) = 220% to 420%
- Void ratio (e) = 5 to 12
- Liquid limit (w_L)= 110% to 460%
- Plastic limit (w_P)= 35% to 120%
- Plastic index (IP)= 75% to 340%
- E_{oed} = 0,15 MPa to 0,45 MPa up to 1,5 MPa
- C_V = 0,3 m²/year to 0,8 m²/year

Ground improvement works

Prefabricated Vertical Drains and Preloading under Runway II

Prefabricated Vertical Drains and Preloading under Runway II

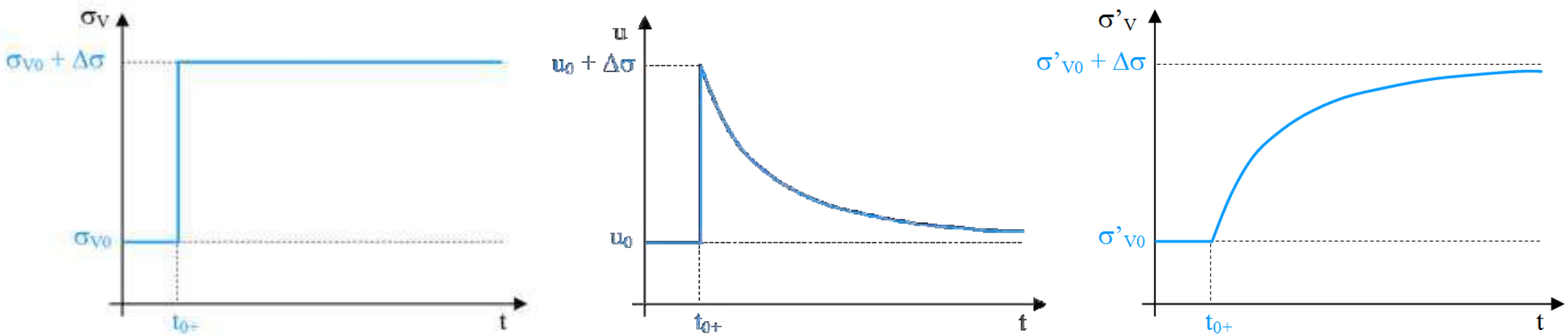
Menard Vacuum Trial Area



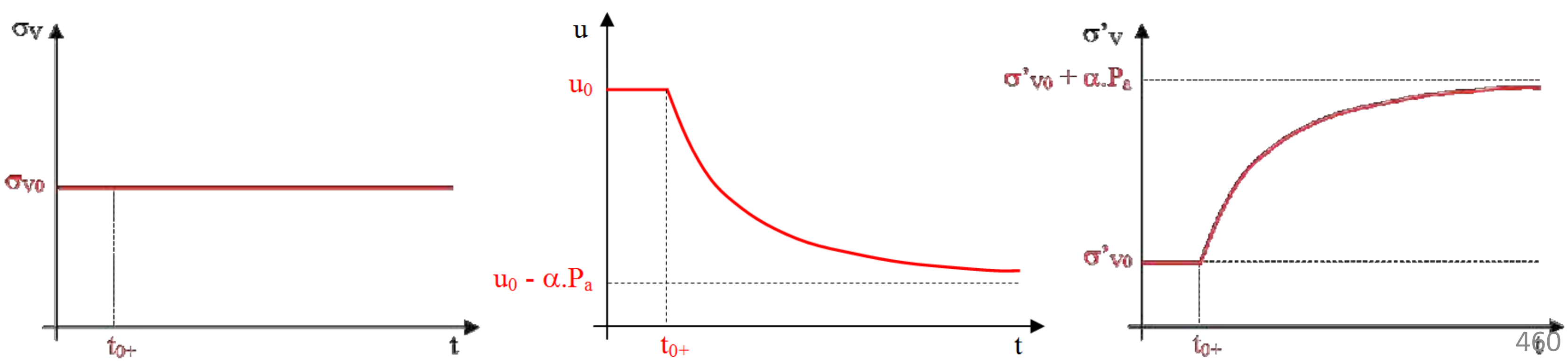
Menard Vacuum Trial Area

$$\sigma' = \sigma - u$$

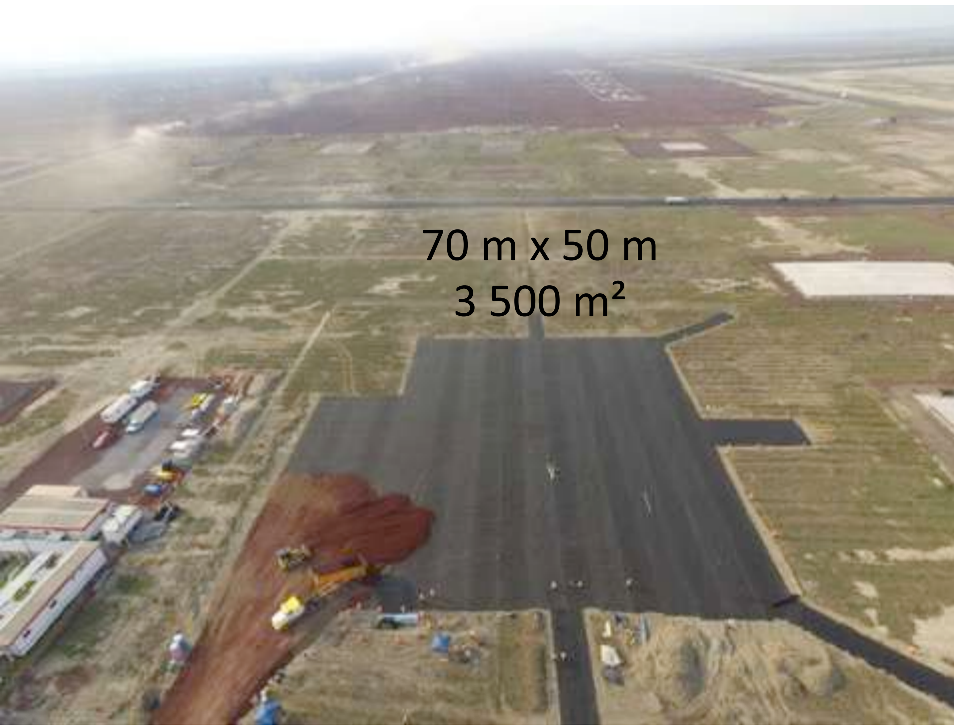
Classical preloading



Vacuum preloading



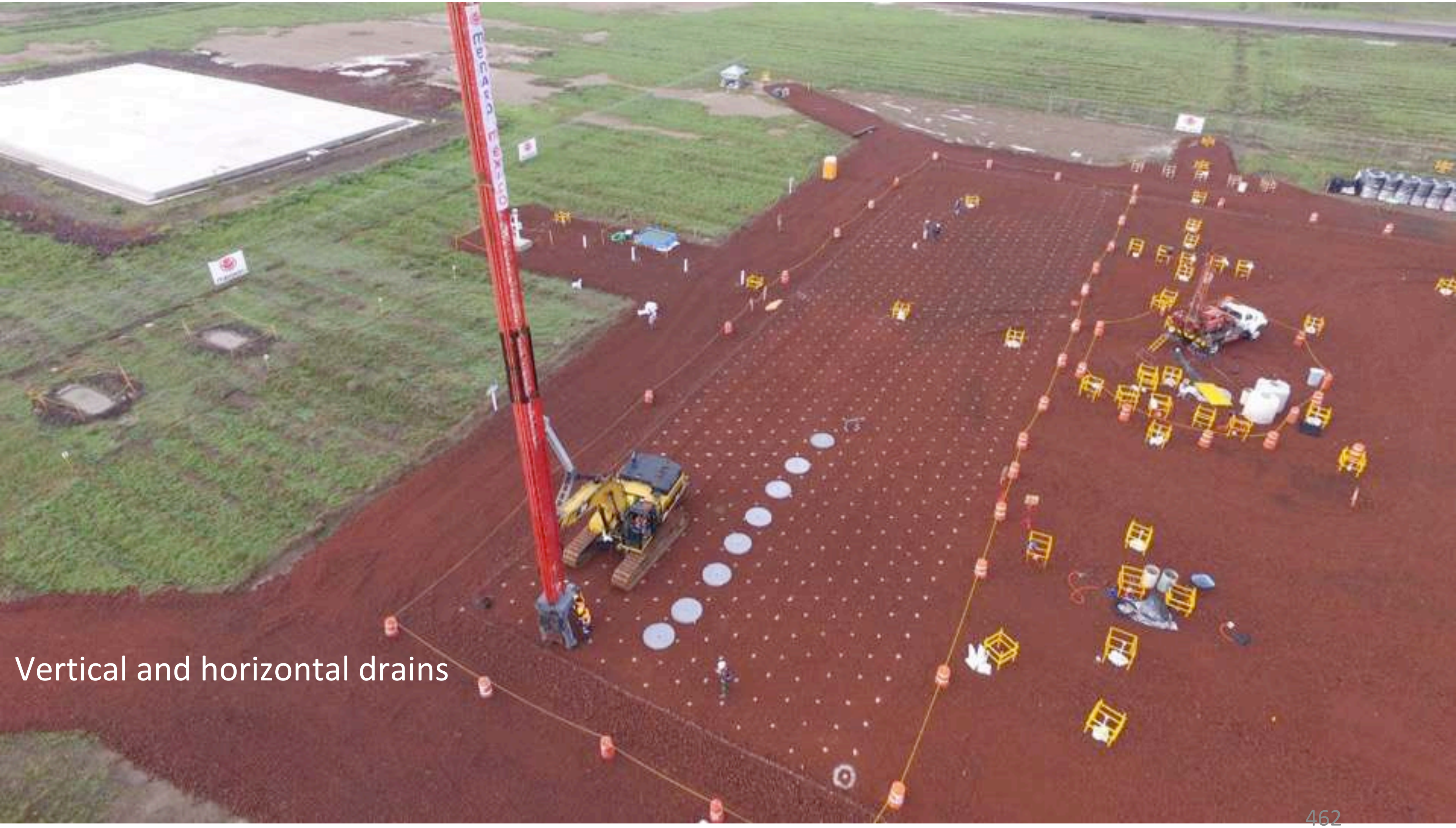
Menard Vacuum Trial Area - Execution



Working platform
0,5 m + 0,5 m = 1 m of “tezontle” (13,7 kN/m^3)

Monitoring installation

Menard Vacuum Trial Area - Execution



Menard Vacuum Trial Area - Execution

Before Vacuum

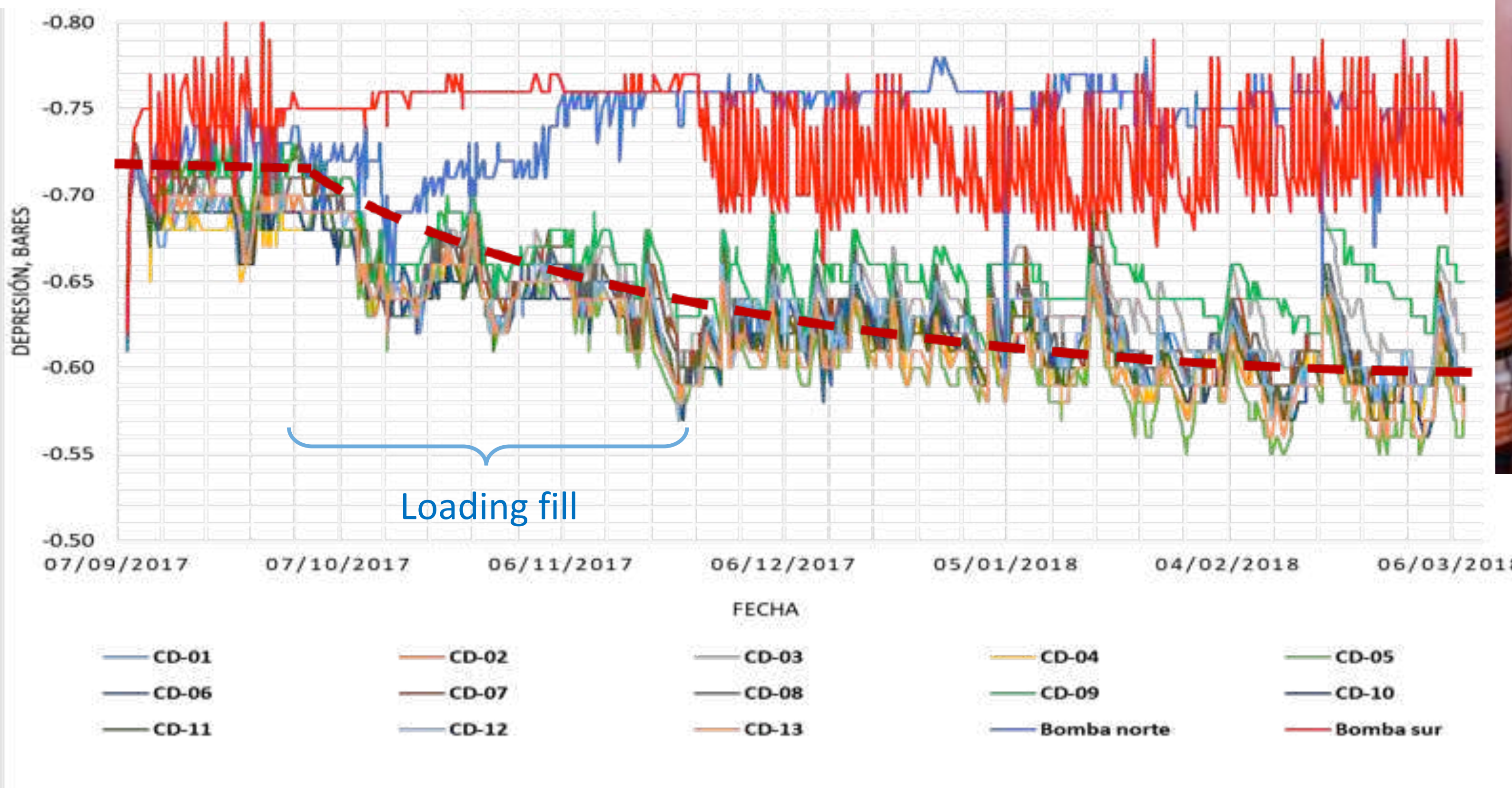
After beginning of Vacuum

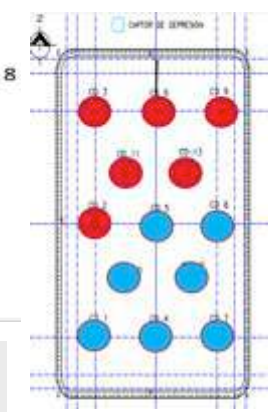
Menard Vacuum Trial Area - Execution

Menard Vacuum Trial Area - Execution

Menard Vacuum Trial Area - Results

Vacuum pressure





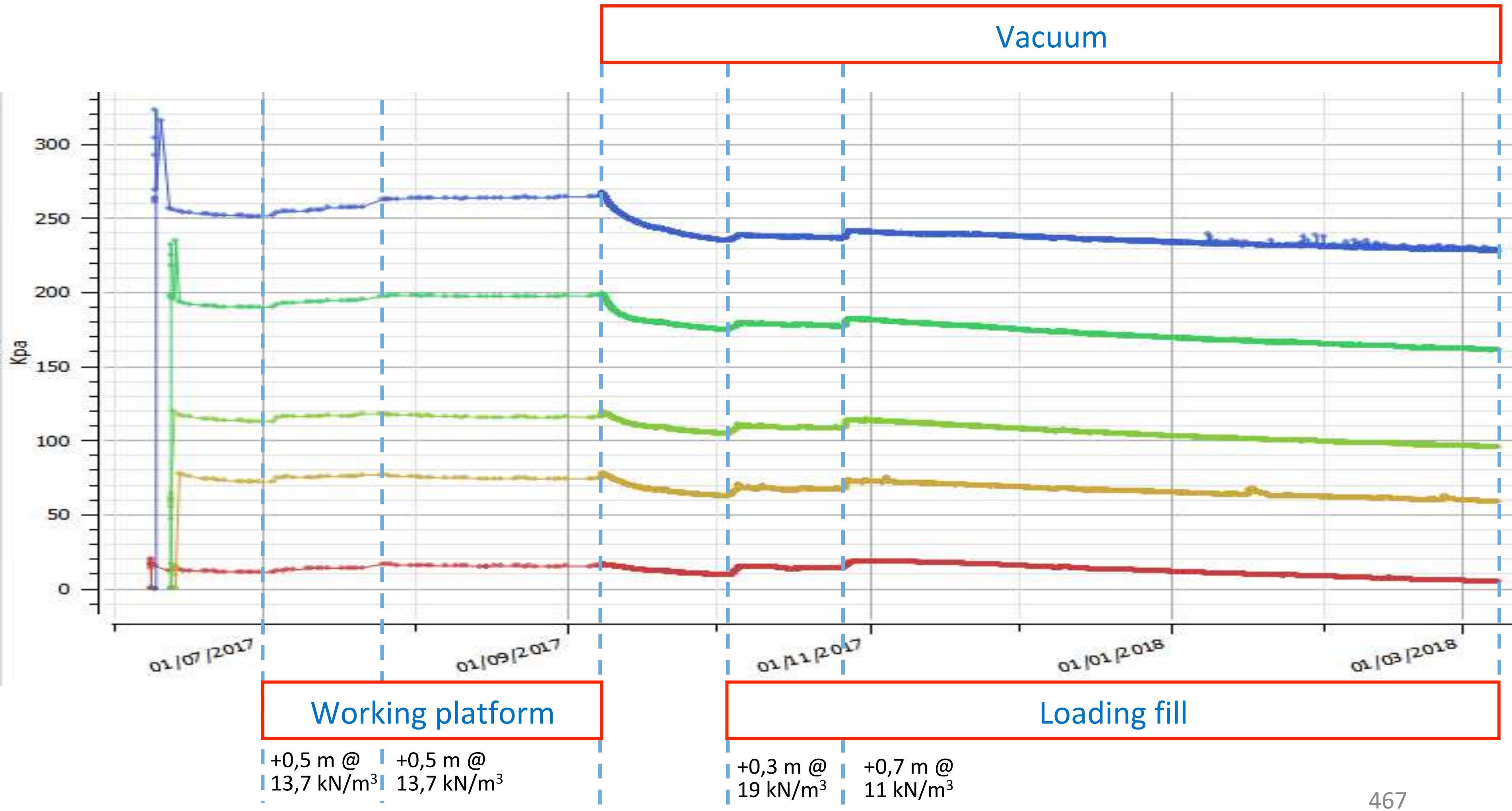
Vacuum pressure = **73 kPa** inside the vacuum pump

Vacuum pressure = **60 kPa** in the soil after 6 months

Note: The atmospheric pressure at the Texcoco Lake (2228 m a.s.l.) is 78 kPa

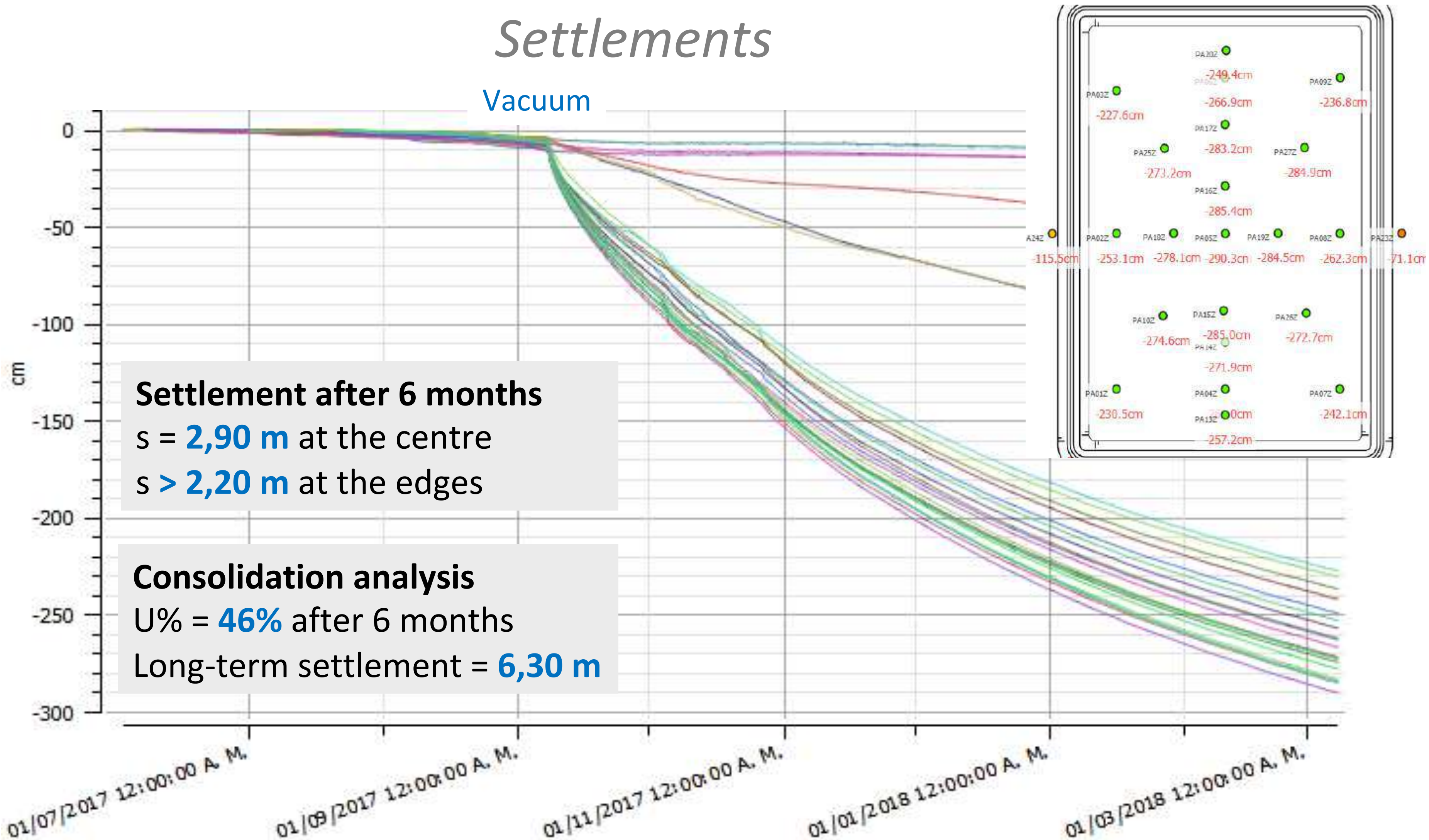
Menard Vacuum Trial Area - Results

Pore Water Pressures



Menard Vacuum Trial Area - Results

Settlements

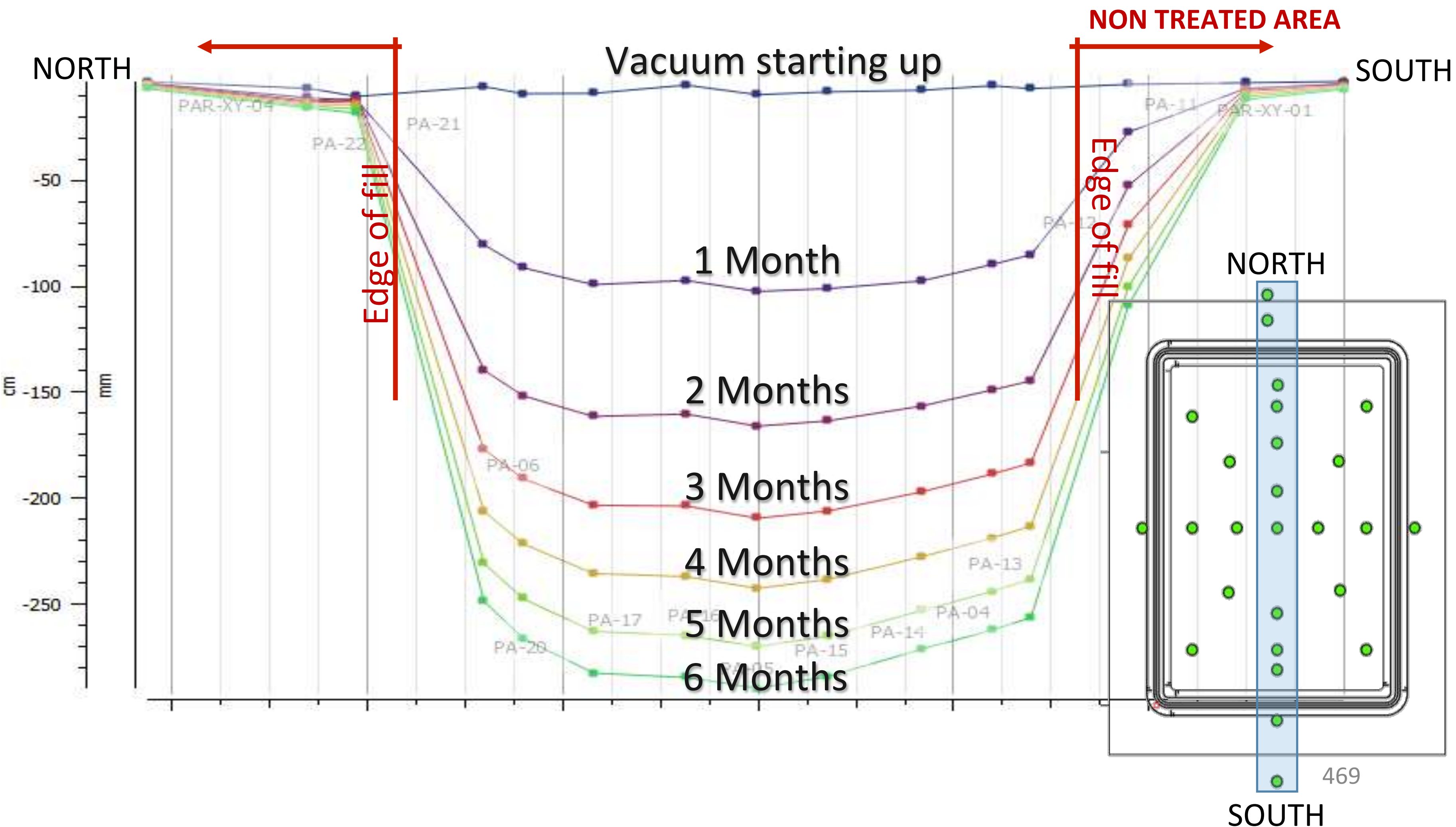


Settlement after 6 months
s = **2,90 m** at the centre
s **> 2,20 m** at the edges

Consolidation analysis
U% = **46%** after 6 months
Long-term settlement = **6,30 m**

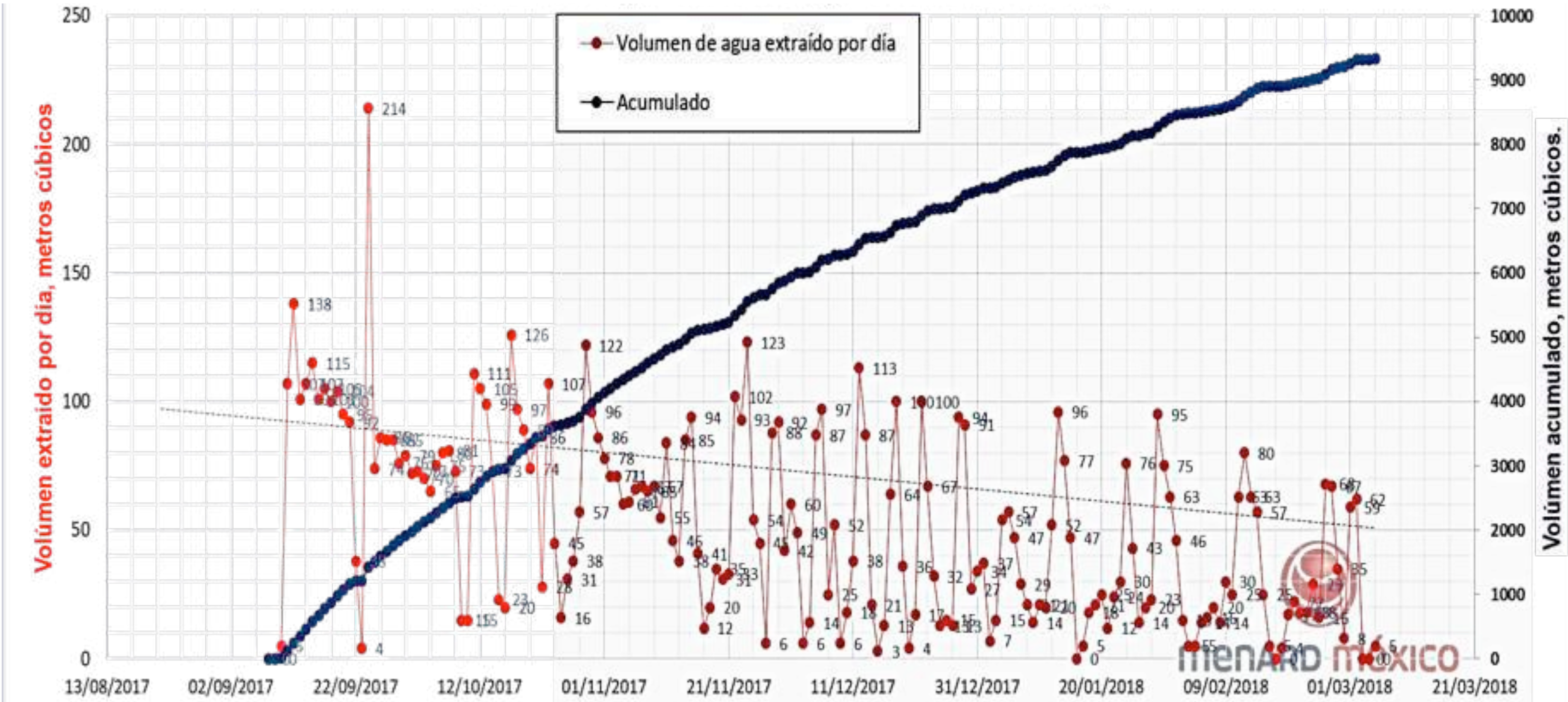
Menard Vacuum Trial Area - Results

Settlements



Menard Vacuum Trial Area - Results

Settlements and extracted water

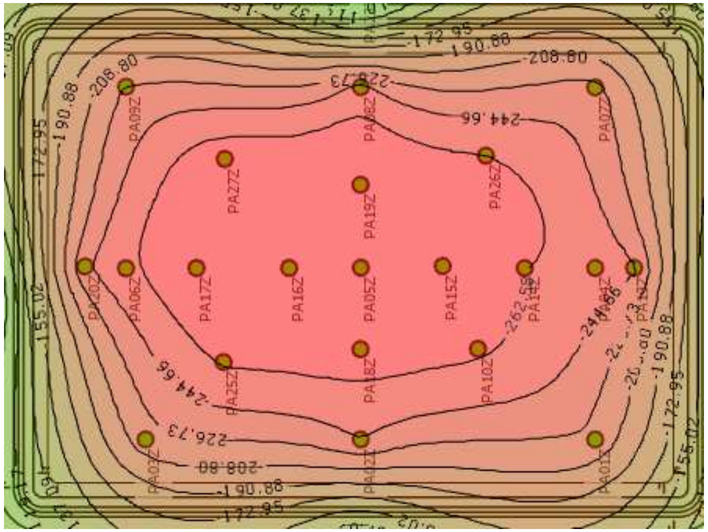


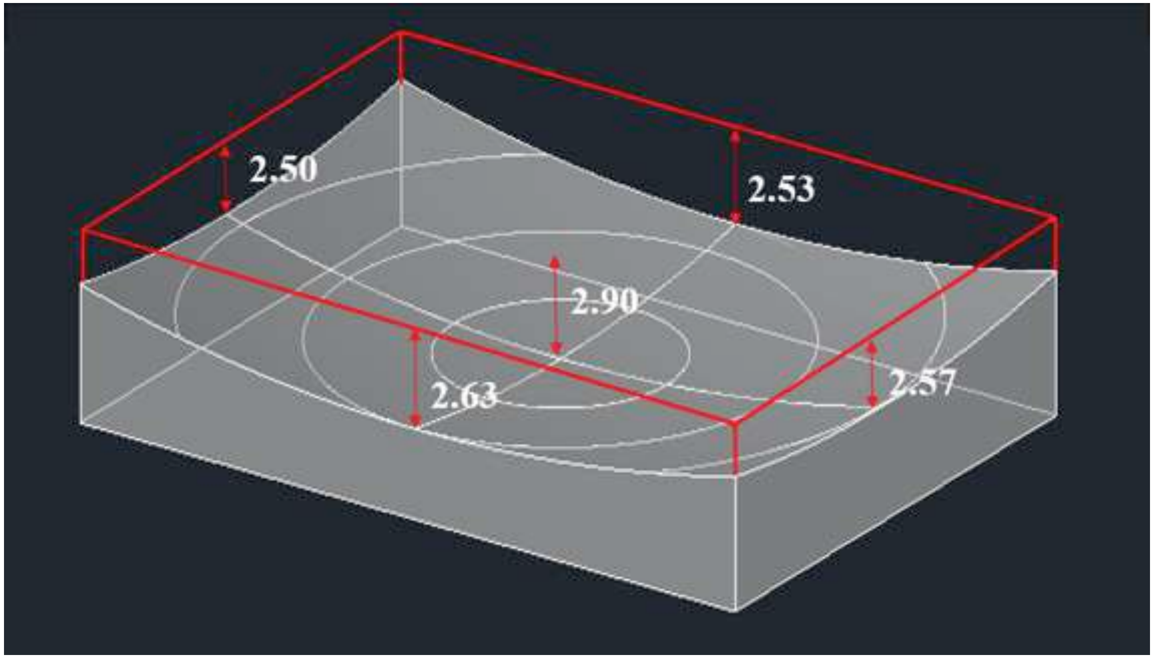
Volume of extracted water

V_{water} = **9 353 m³**

Menard Vacuum Trial Area - Results

Settlements





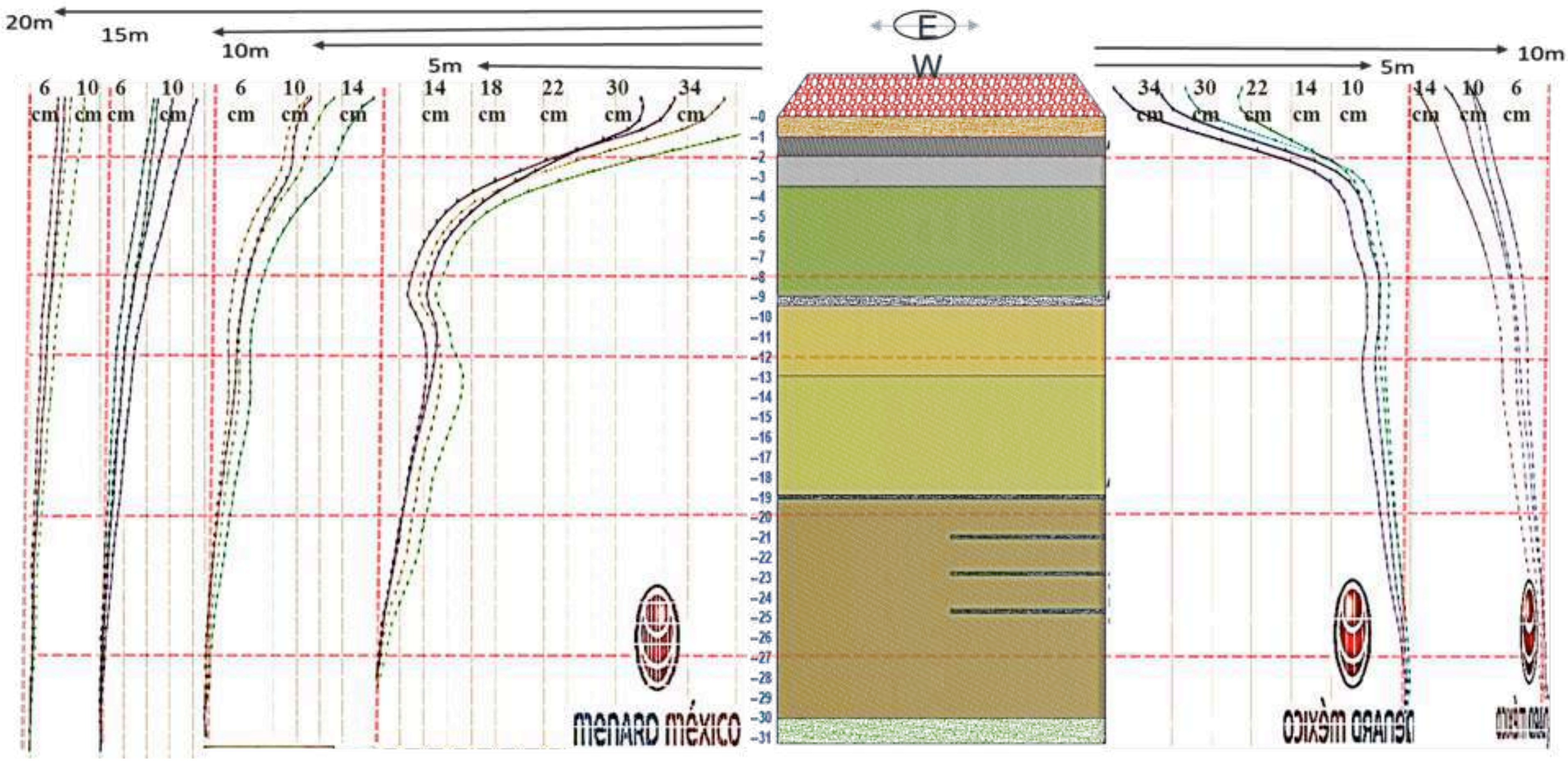
Volume of extracted water
V_{water} = **9 353 m³**

Volume of settlement
$V_{settlement}$ = **9 628 m³**

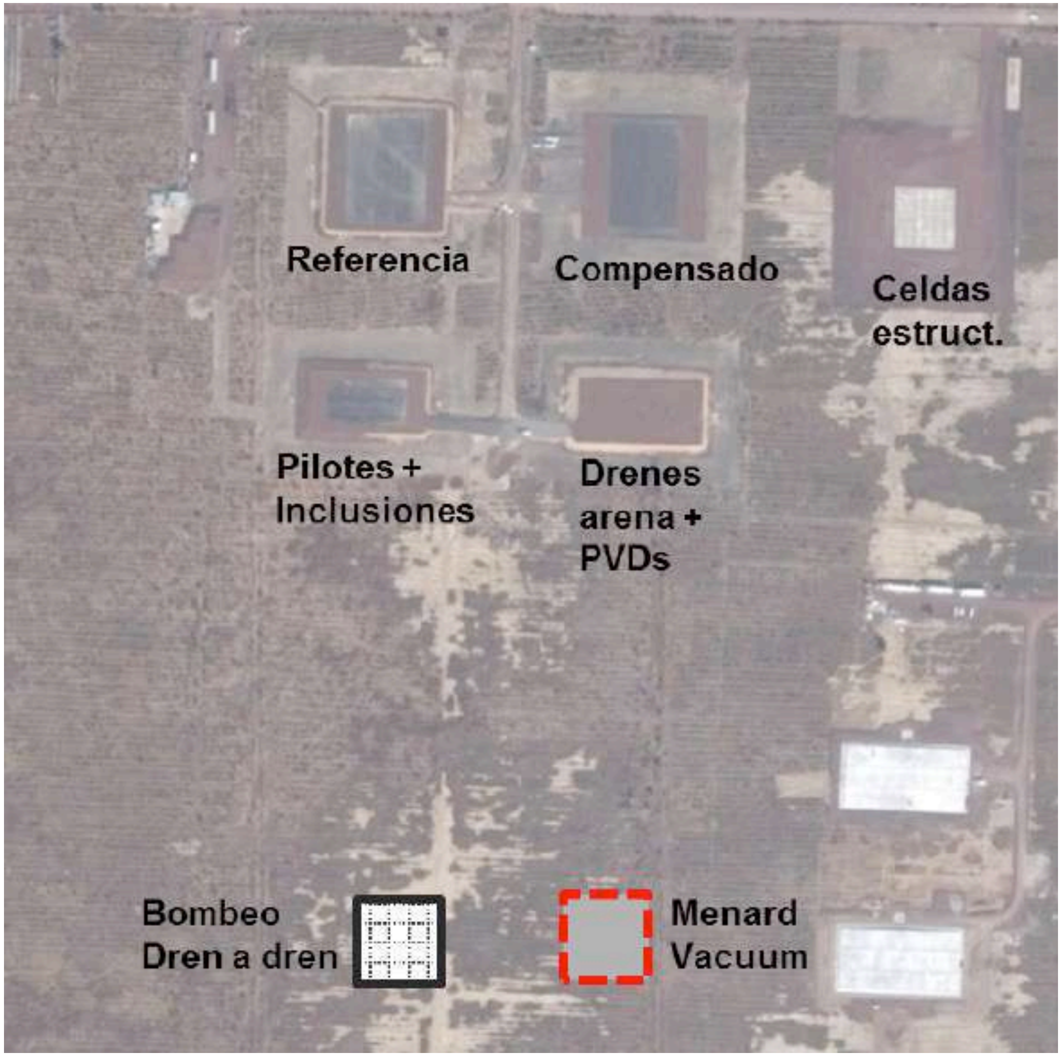
The amount of extracted water is equal to the total settlement. Menard Vacuum Consolidation method has nothing to do with dewatering.

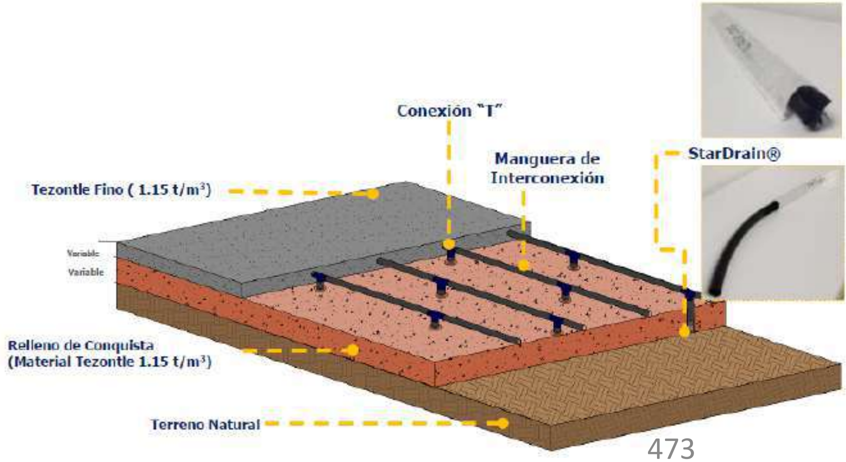
Menard Vacuum Trial Area - Results

Lateral displacements

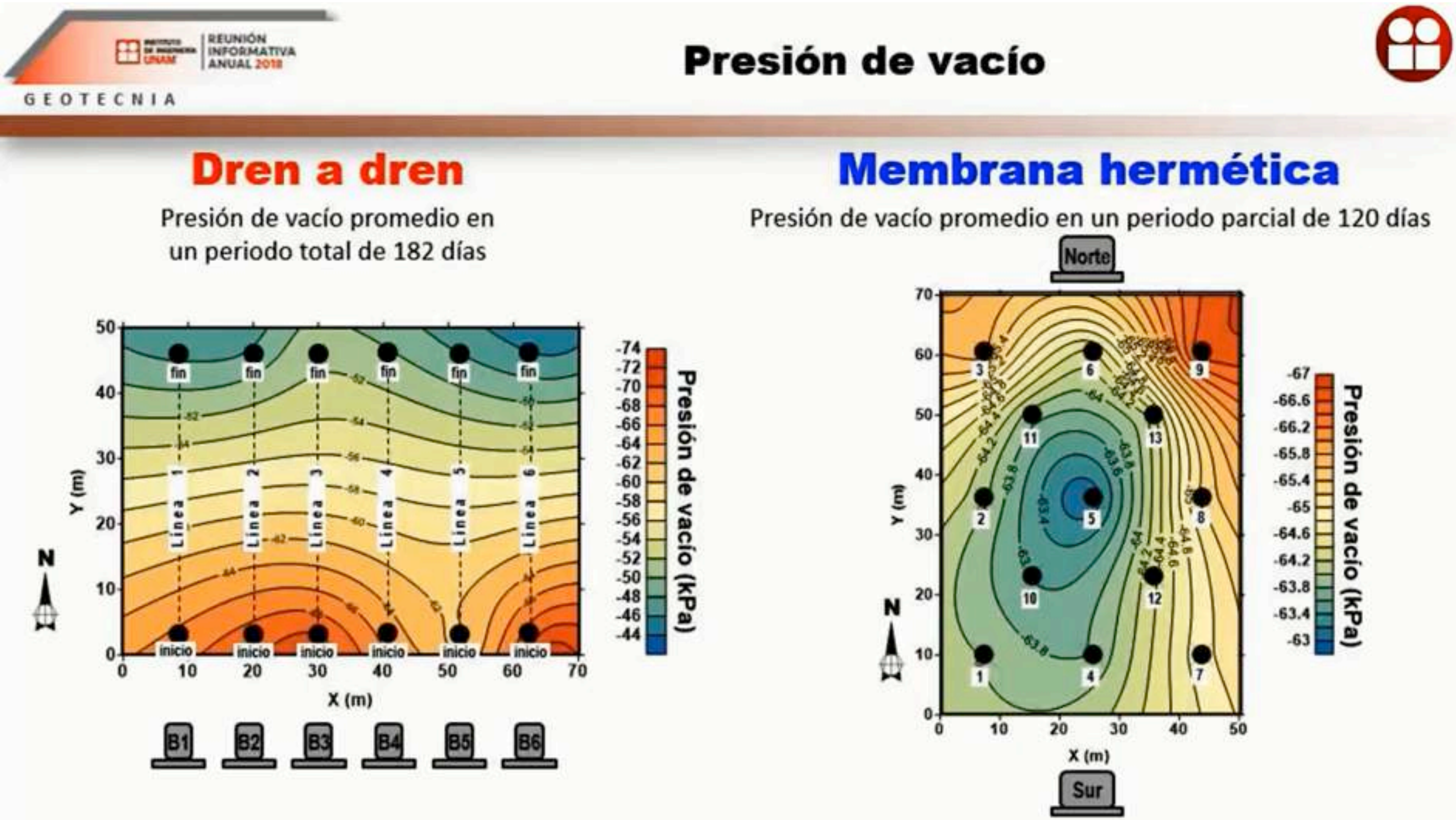


Menard Vacuum Trial Area **vs** Drain to Drain Trial Area

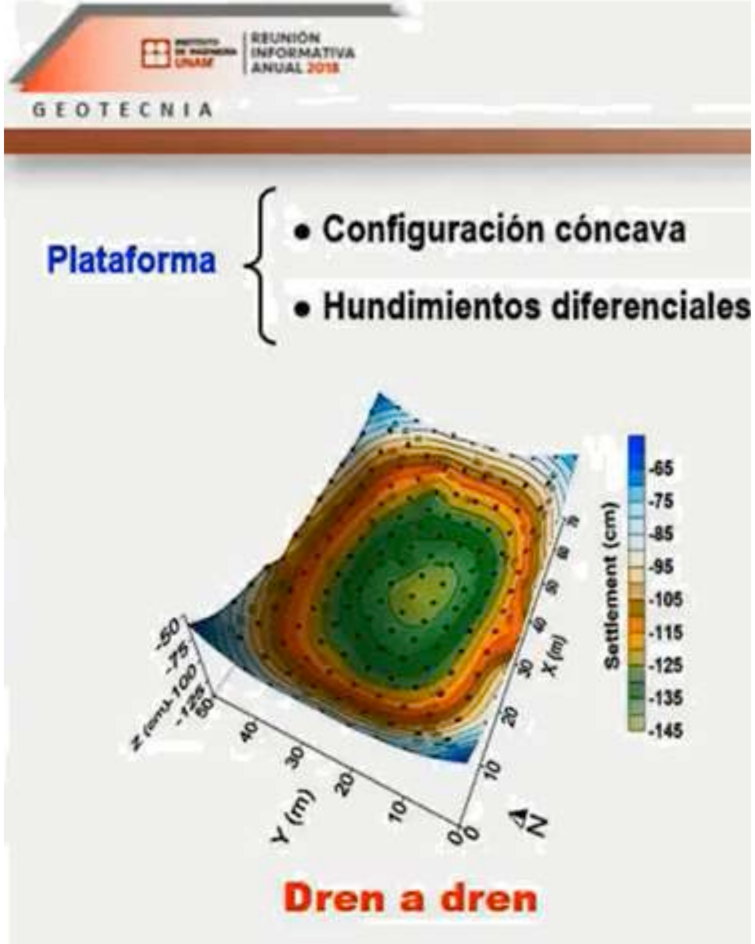




Menard Vacuum Trial Area **vs** Drain to Drain Trial Area



Menard Vacuum Trial Area **vs** Drain to Drain Trial Area



Settlements
2,00 m at the centre
1,20 m at the edges

Differential settlements along the transverse centerline

Fig.10 summarizes data obtained from the horizontal inclinometer. Curves evidence isochronic settlement profiles that have almost symmetrical shapes and trends similar to that exhibited by traditional embankments. The differential settlements between the center and the boundaries of the embankment are influenced by the inward movements of the lateral boundaries caused by vacuum. Boundary settlements vary linearly with the corresponding ones detected at the centre. Along the transverse centerline a ratio equal to 0.6 between lateral and central settlements was observed: this value is practically coincident with that predicted by the elastic theory for traditional embankments.

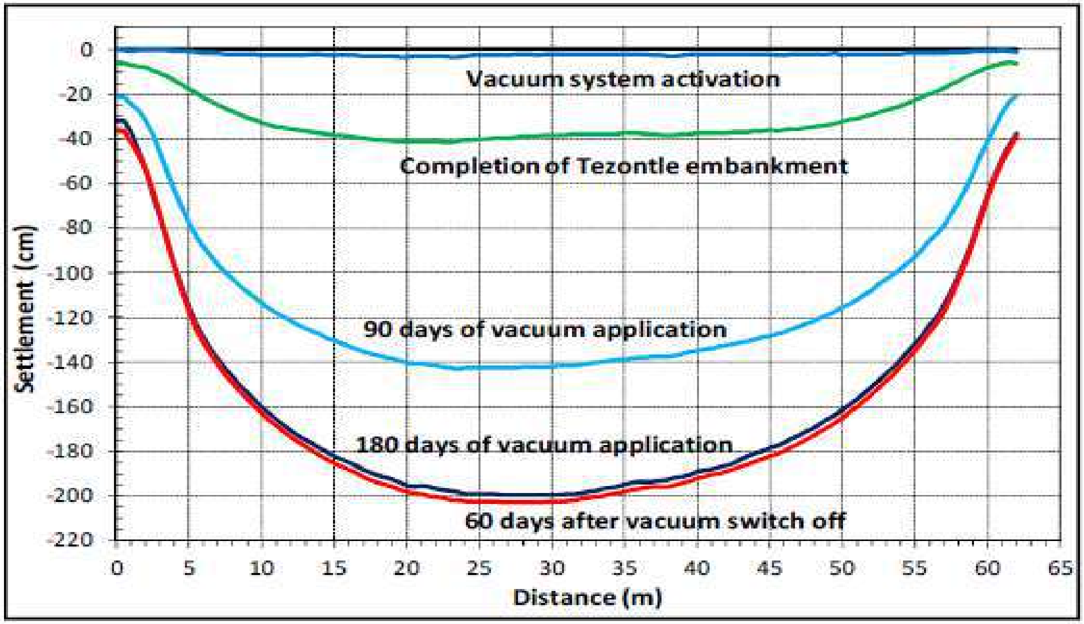
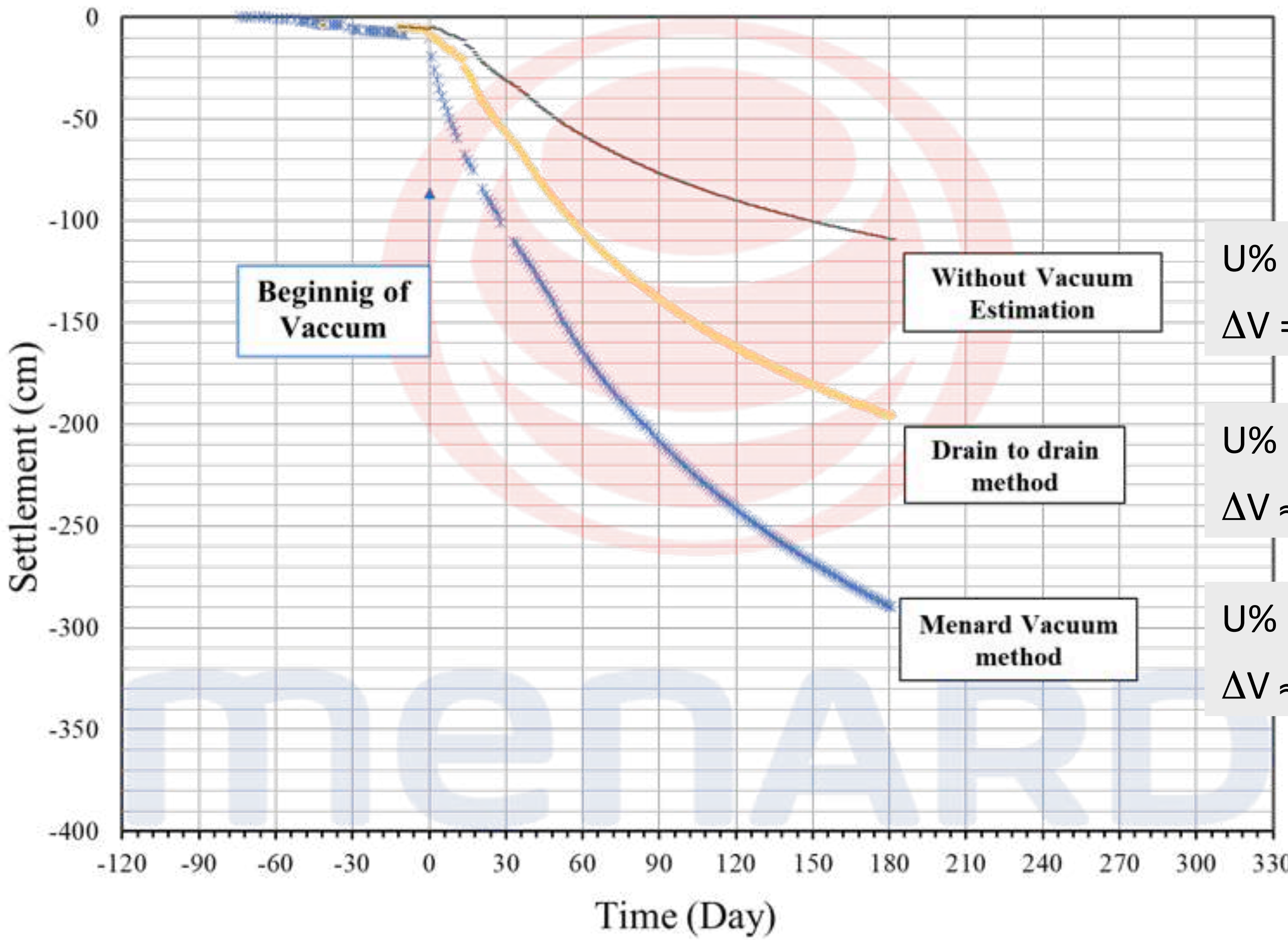


Fig 10 – Time history of settlements measured by horizontal inclinometer

Menard Vacuum Trial Area **vs** Drain to Drain Trial Area



U% = **46%**

ΔV = **0 kPa**

U% = **46%**

ΔV ≈ **27 kPa**

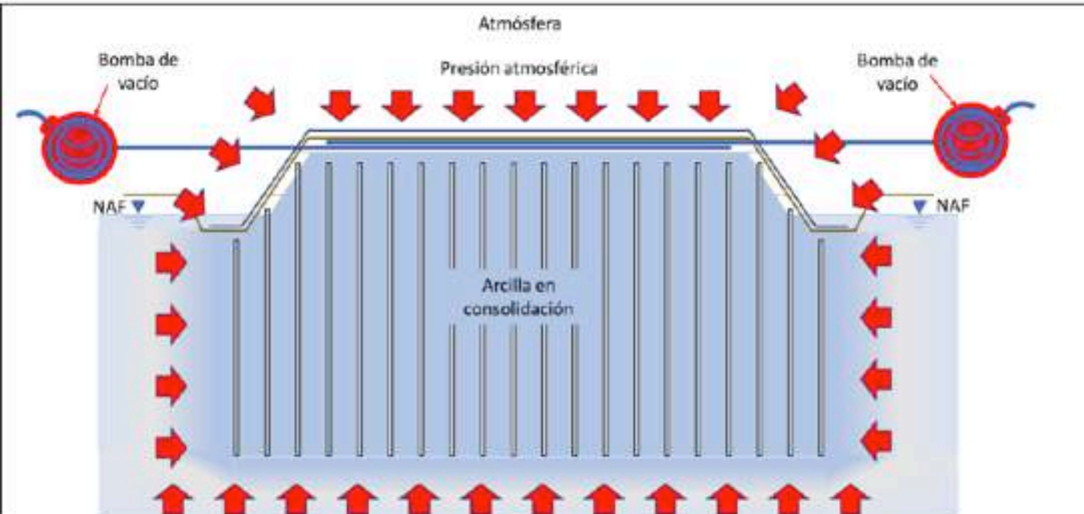
U% = **46%**

ΔV ≈ **60 kPa**

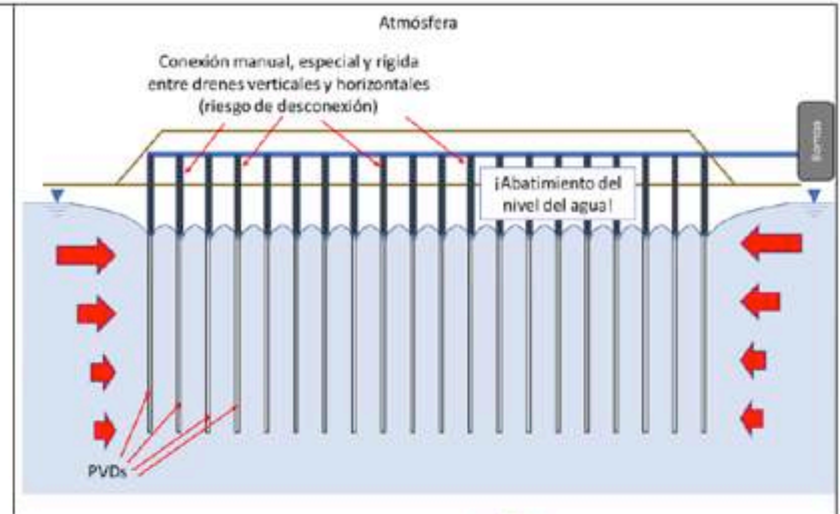
Menard Vacuum Trial Area **vs** Drain to Drain Trial Area

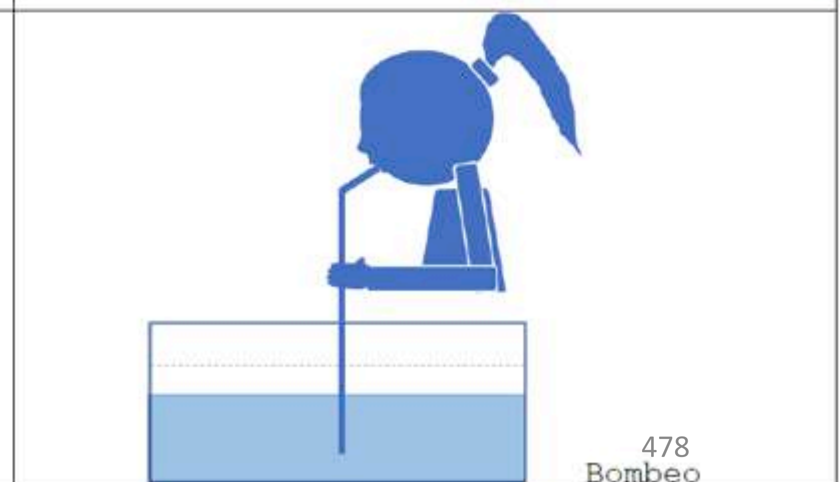
Menard Vacuum Trial Area **vs** Drain to Drain Trial Area

Menard Vacuum Consolidation method



Drain to Drain method





Obrigado!

Thank you!

Merci!

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Challenges in ground improvement research

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FACHHOCHSCHULE
ERFURT UNIVERSITY
OF APPLIED SCIENCES

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Apoios

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

ORDEM DOS ENGENHEIROS

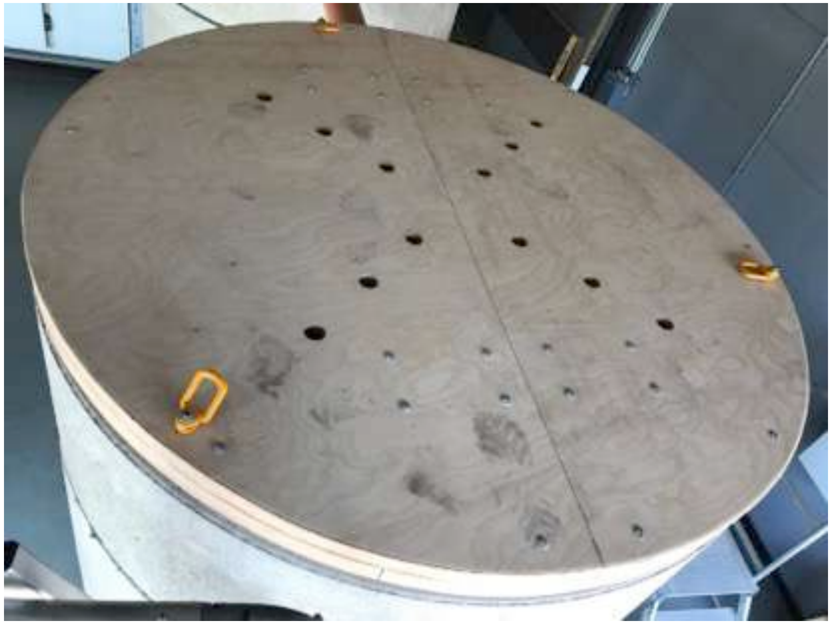
Contents

- Optimization of vibro compaction
- Grain crushing due to depth vibrators
- Filter stability of vibro stone columns
- Further challenges

Vibro compaction: model test cylinders

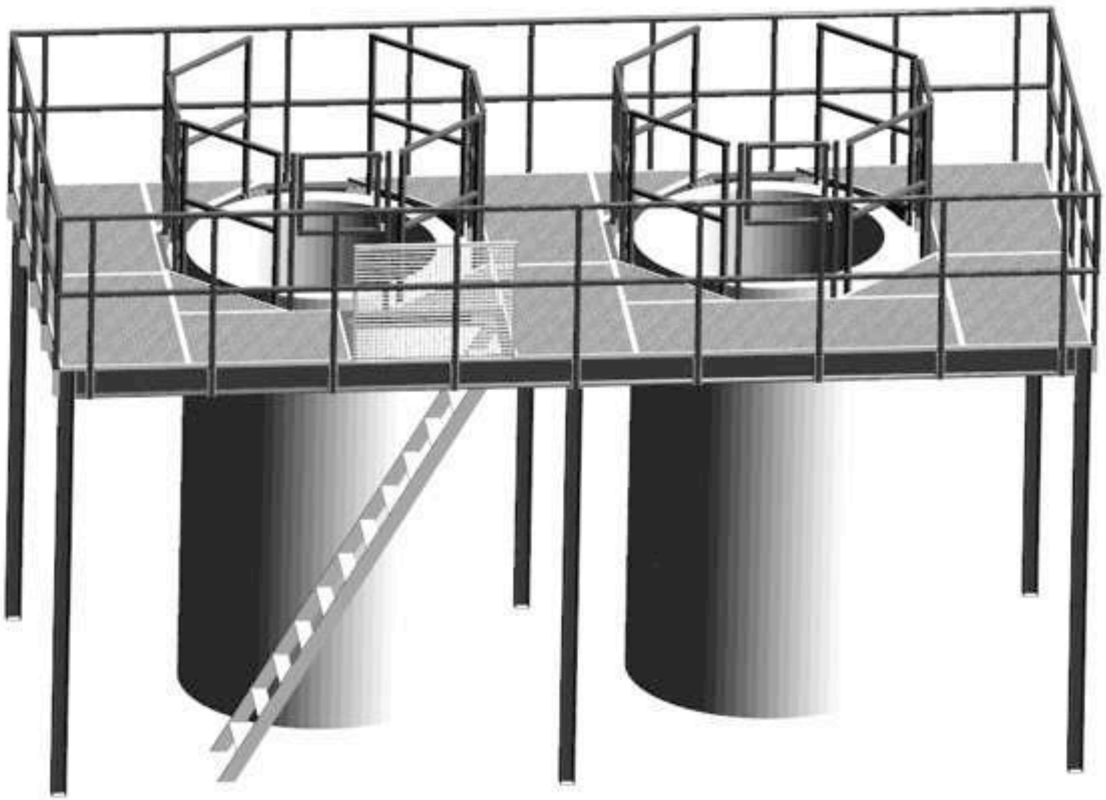
Vibro compaction: model test device

drainage



wooden plate with holes for dynamic probing tests

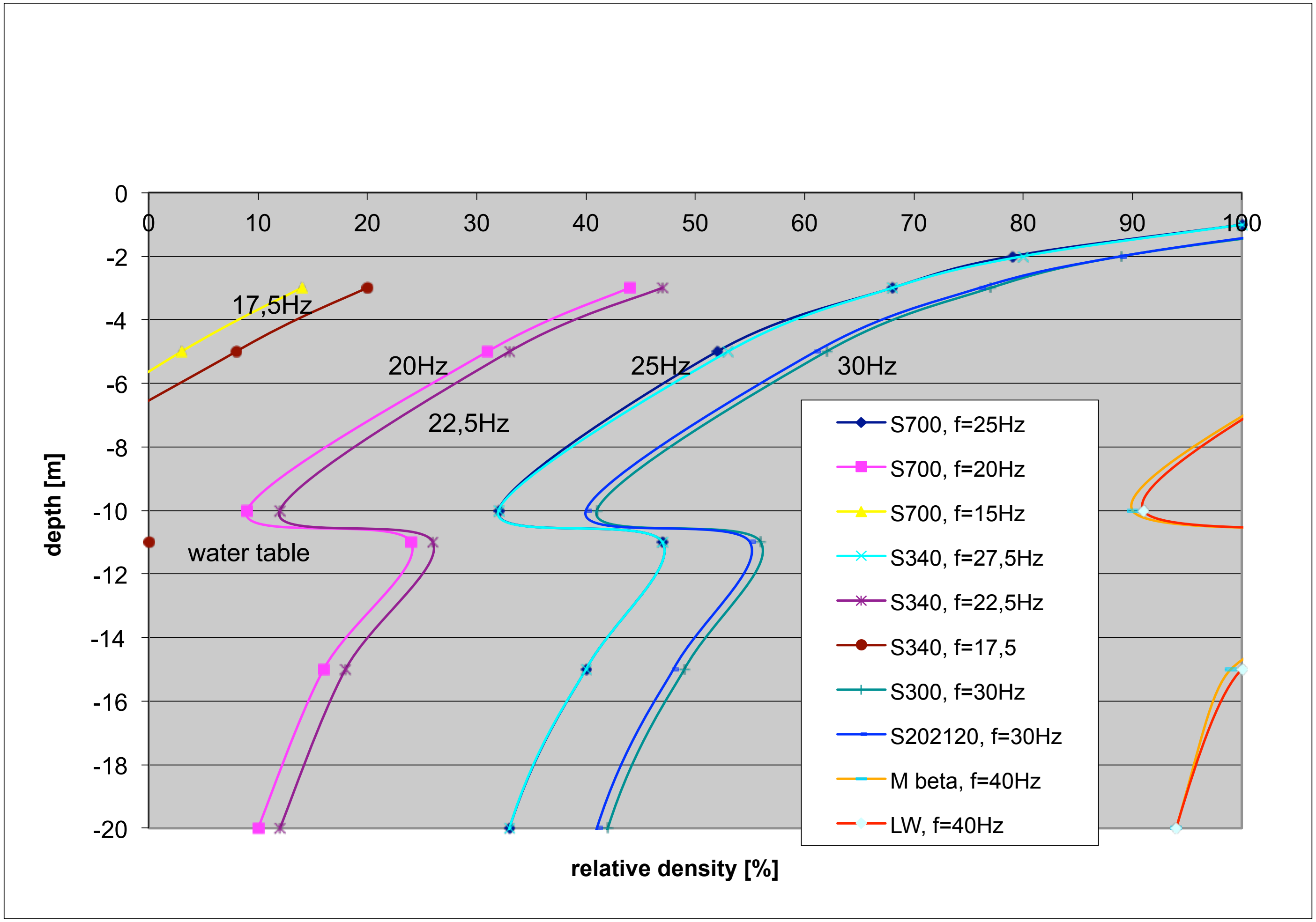
Vibro compaction: working platform



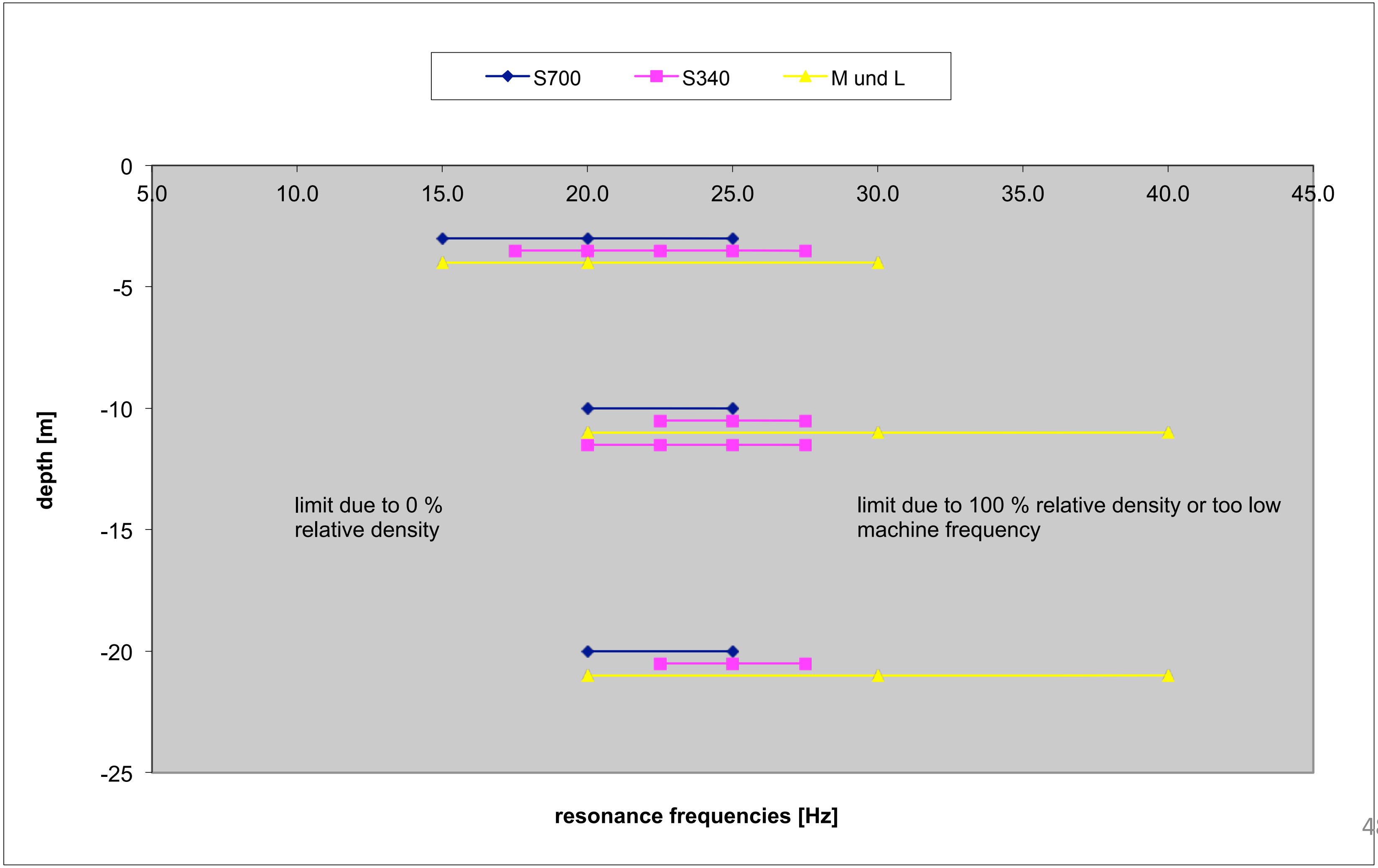
design (master thesis)

Vibro compaction: test of depth vibrator

Vibro: resonance frequencies of different depth vibrators



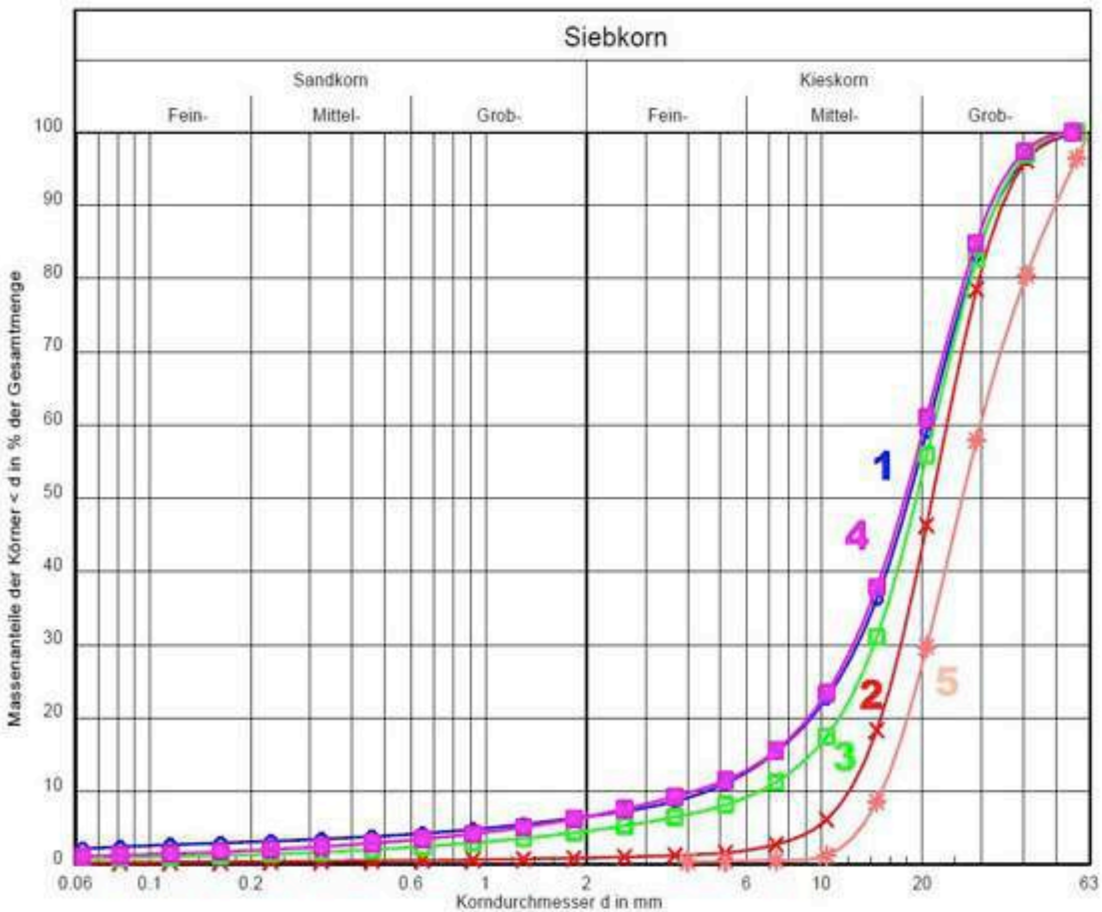
Vibro: Limitation of resonance frequencies



Vibro: resonance

- Does resonance of pure soil exist?
- Can vibrator amplitudes in the soil be larger than amplitudes in the air?
- Is amplitude control possible by the crane operator?

Grain crushing due to depth vibrators



- 1. vibro stone column
- 2. Proctor with gravel
- 3. modified Proctor with gravel
- 4. modified Proctor M-vibrator with gravel
- 5. gravel delivered to site

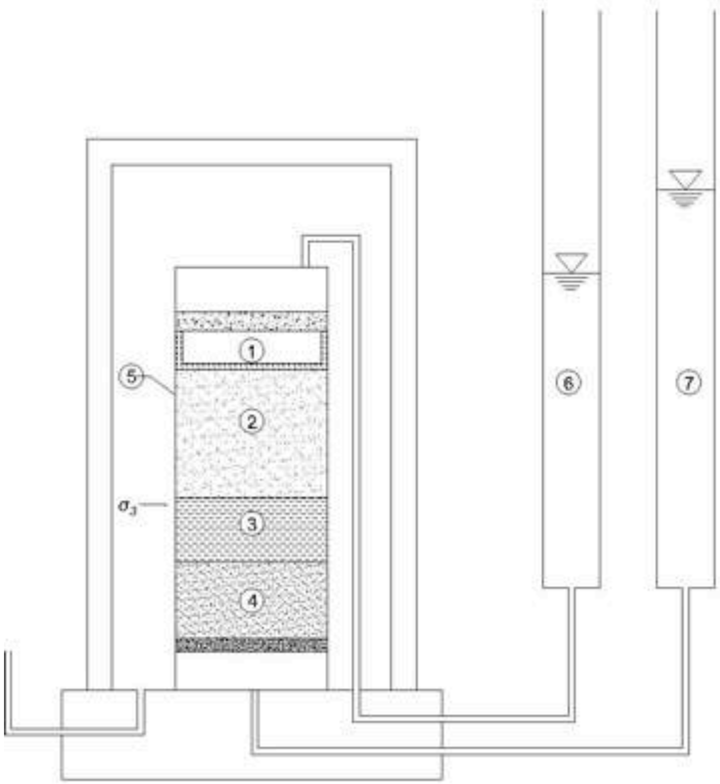
Grain crushing due to depth vibrators

Proctor	Proctor test	modified Proctor test	modified Proctor M-vibrator	modified Proctor S-vibrator
Mass falling weight	2.5 kg	4.5 kg	4.5 kg	4.5 kg
Diameter falling weight	50 mm	50 mm	50 mm	50 mm
Falling height	305 mm	457 mm	457 mm	457 mm
Number of layers	3	5	5	5
Number of blows / layer	56	56	71	178
Volume of test cylinder	2208.93 cm^3	2208.93 cm^3	2208.93 cm^3	2208.93 cm^3
Compactions energy	0.569 MNm/m^3	2.557 MNm/m^3	3.242 MNm/m^3	8.106 MNm/m^3

Grain crushing due to depth vibrators

- Grain crushing of depth vibrators is modelled by modified Proctor test in the laboratory
- New modified parameters are determined with standard tests (oedometer – Es- constrained modulus, simple shear – friction angle phi)
- Es is usually larger than 200MN/m^2 because of reloading
- Phi is usually larger than 45^o because of large grains

Vibro stone columns: filter stability

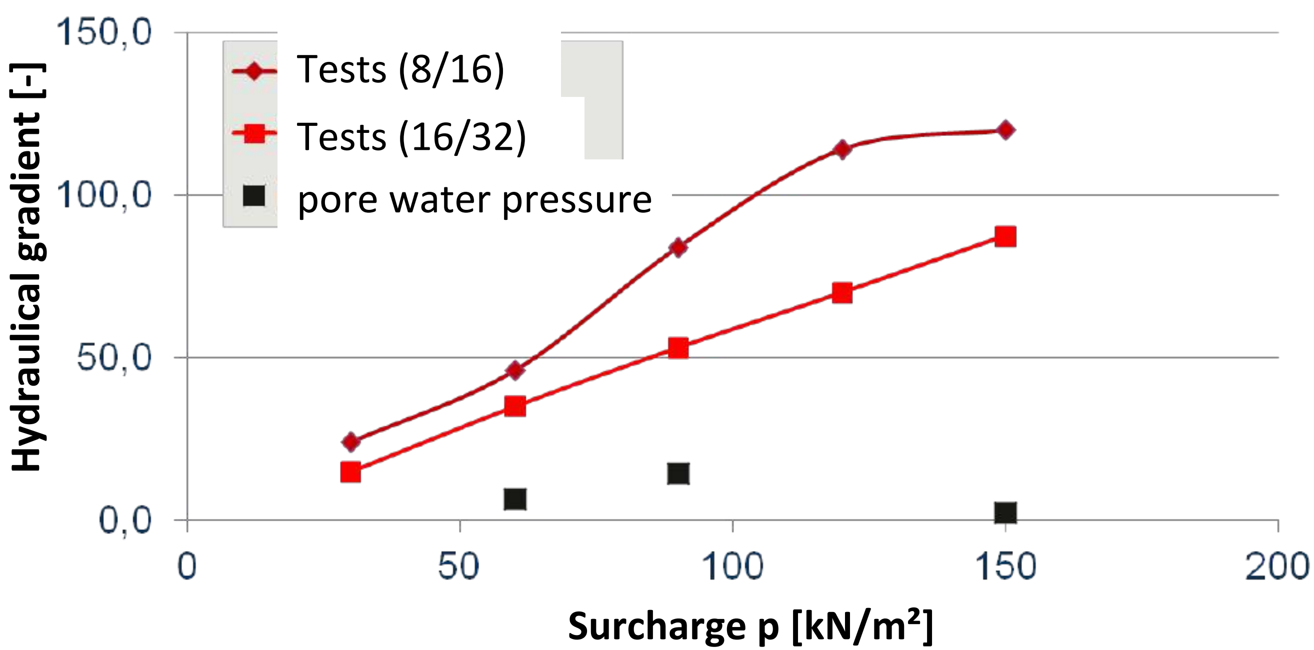


acrylic glass with many small soil particles in the water = critical hydraulic gradient

1 acrylic glass
2 sand
3 clay
4 sand base
5 latex coating
6 water level outlet
7 water level inlet

Vibro stone columns: filter stability

Construction project	Soil	Depth of sensor [m]	Distance b. sensor & RSS [m]	Excess Porewater pressure [kPa]	Hydraulical gradient [-]
Melle	TL, w-st	7.5	1.40	33.8	2.4
Bremen	TL, br-w	3.2	0.78	51.6	6.6
Klagenfurt	SU*	5.0	0.76	108.0	14.2



Vibro stone columns: filter stability

- Filter stability criteria (Terzaghi) not valid for gravel-clay interface
- Hydraulical gradients generated by excess pore water pressure are considerably lower than laboratory (Munich and Erfurt university) values
- During column installation the excess pore water pressure is not high enough to start the erosion process around vibro stone columns in cohesive soil

Further challenges

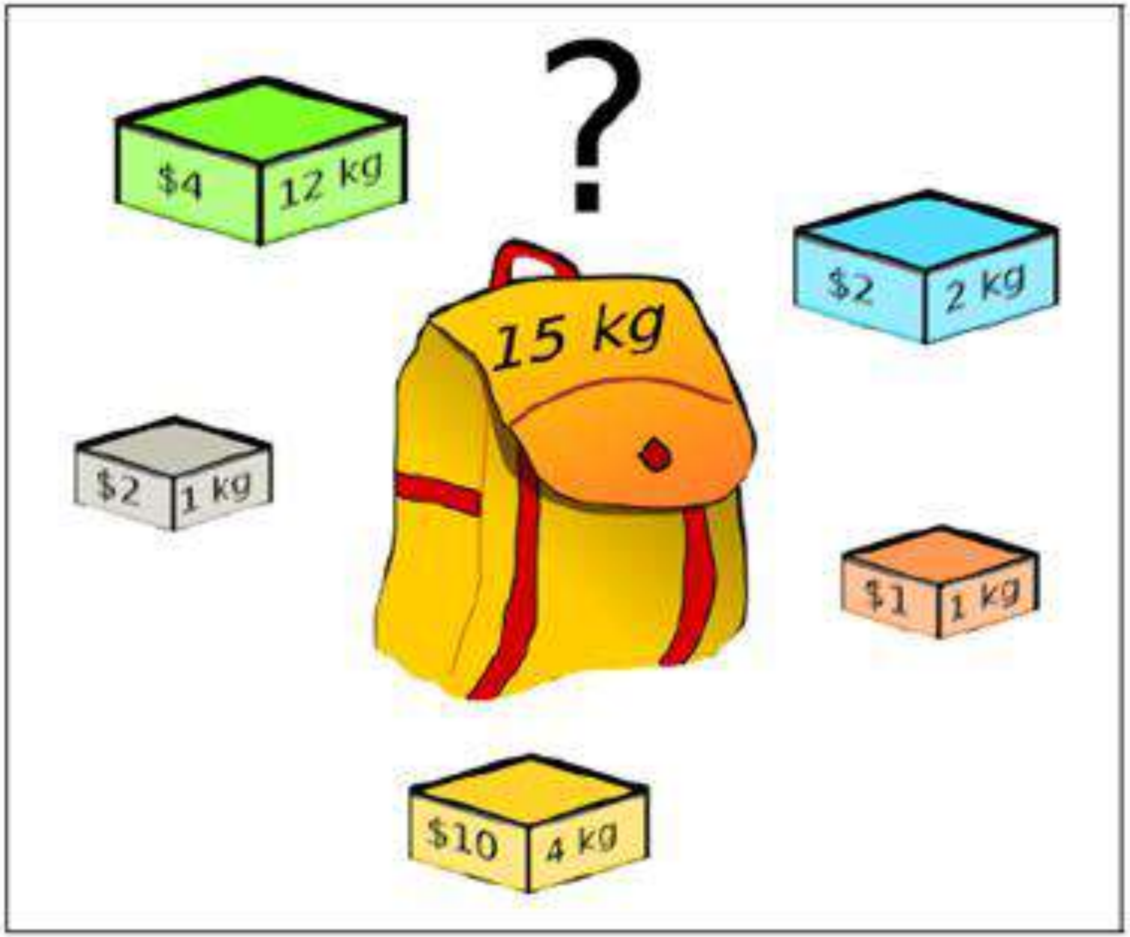
- Multi-criteria optimization of stone / concrete columns (costs vs. settlement) – IT-interface

- What is Multi-criteria optimization?
  - An optimization with different variables, i.e.
    - Column length
    - Column diameter
    - Column grid
    - Thickness of load distribution layer
    - .....
  - Multiple calculations
  - An optimization algorithm finds the optimal solution
  - Short calculation time

  - Theory: results of Edgeworth-pareto-front

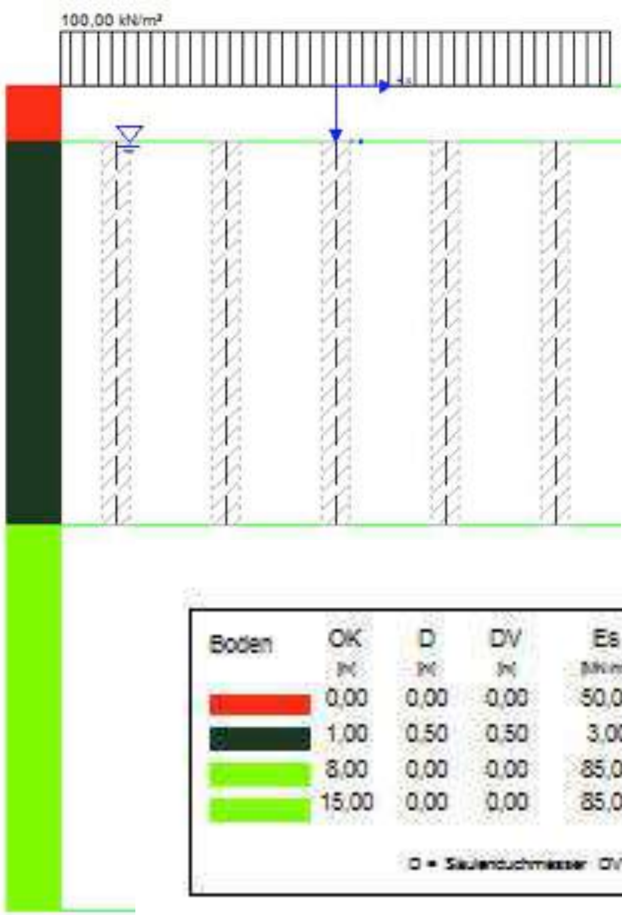
Further challenges

- Multi-criteria optimization: backpack (Dantzig 1940)



Further challenges

- Multi-criteria optimization: soil profile / parameters with vibro stone columns

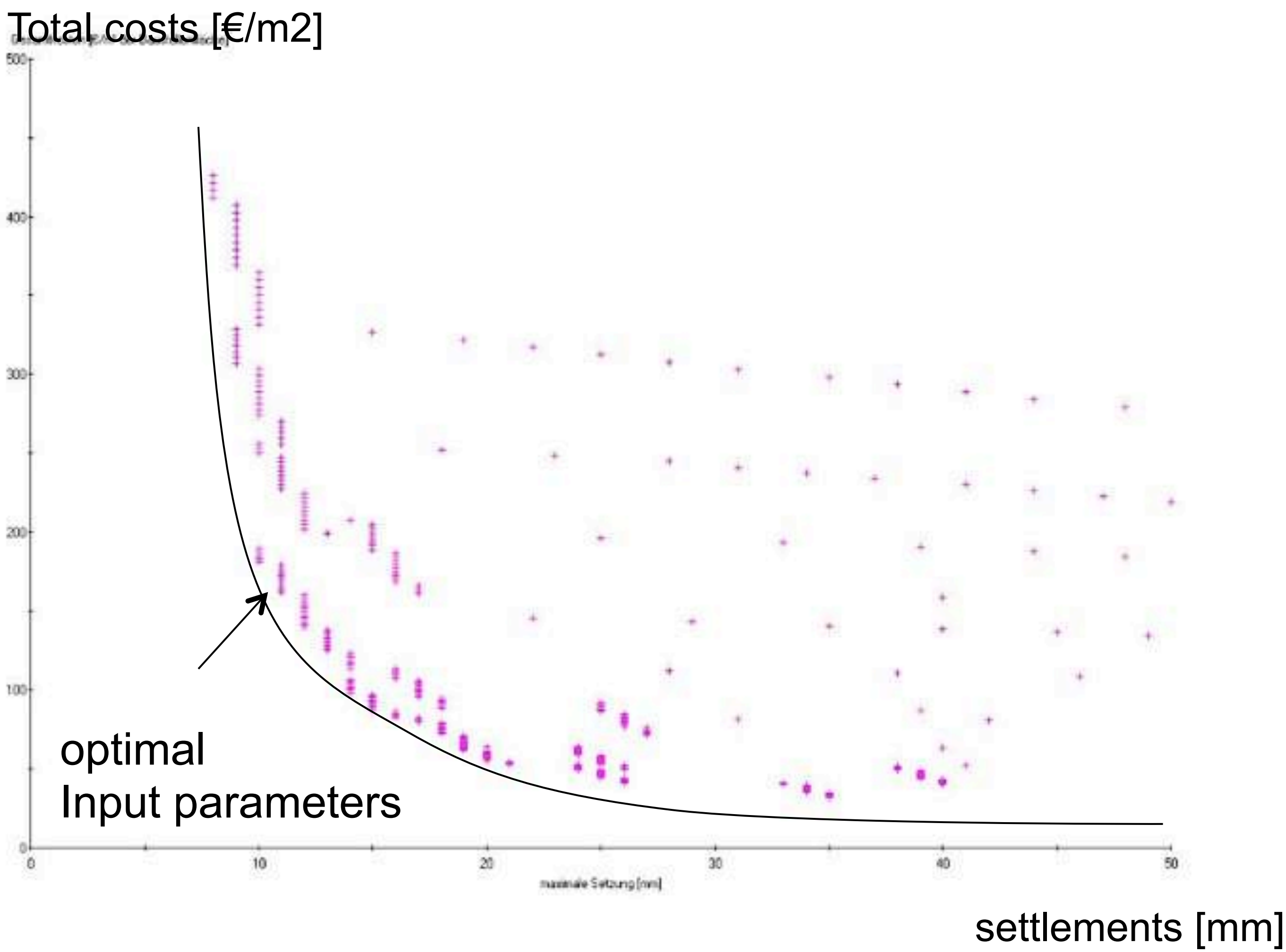


Boden	OK [m]	D [m]	DV [m]	Es [MN/m²]	γ [kN/m³]	φ [°]	c [kN/m²]	ν [-]	Bezeichnung
(red)	0,00	0,00	0,00	50,00	19,00	35,00	9,00	0,33	Sand
(dark green)	1,00	0,50	0,50	3,00	10,00	25,00	5,00	0,40	Schluff
(green)	8,00	0,00	0,00	85,00	11,00	35,00	0,00	0,33	Sand
(green)	15,00	0,00	0,00	85,00	11,00	35,00	0,00	0,33	Sand

D = Säulendurchmesser DV = Durchmesser Verbundsäule

Further challenges

- Multi-criteria optimization: results



Further challenges

- Leckage of excavation pits

Further challenges

- Leckage of excavation pits

Water dosage

Thermo-hydrograph

admissible amount of water
1.5 l/s and 1000m²

Photo documentation

Further challenges

- Leckage of excavation pits
  - Determination of wet area in the laboratory depending on temperature, moisture content in the air, wind speed, wall roughness …
  - Comparison of wet area in laboratory and on site
  - Analytical formula to calculate wet area will be developed

Further challenges

- Suitability of ground improvement methods during earthquake with/without soil liquefaction
- Optimierung of penetration of top vibrator systems with tube / sheet pile /... – mechanical engineering interface
- …

Summary

Optimization of vibro compaction with frequency control

Change of column design parameters depending on compaction energy due to grain crushing

Evaluation of critical hydraulic gradient to ensure filter stability of vibro stone columns. Modification of testing device.

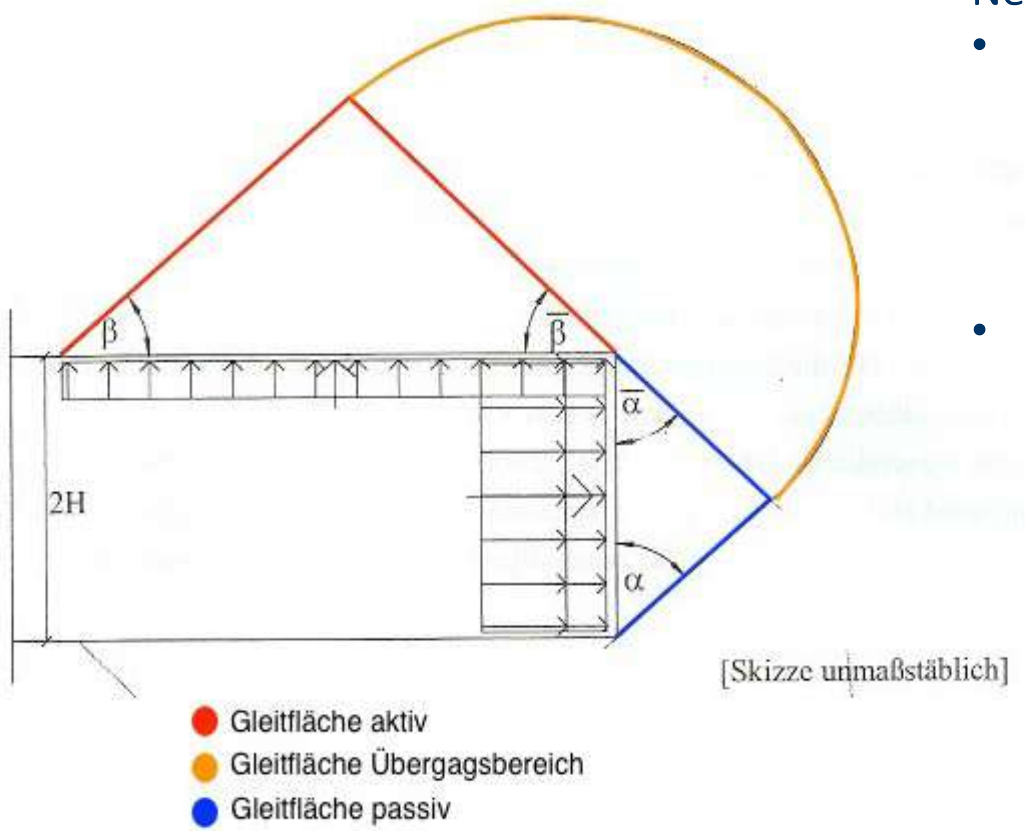
Realistic design of jet grout column diameter due to consideration of new parameters

Jet grouting: combination of analytic approaches

of

1. Bernd Bergschneider (Wuppertal): maximum diameter
2. Jürgen Stein (Hamburg): development of diameter vs time

Jet grouting: design of column diameter



New items

- pore water pressure depending on soil permeabilty (consolidation calculation to built of excess pore water pressure) and
- cohesion of soil along the shear zones

Jet grouting: design of column diameter

- Analytical formula to calculate column diameter will be developed depending on
  - jet grouting machine parameters
  - jet grouting execution parameters
  - soil and water parameters

Application of Geotextile Encased Columns (GECs) in embankment over soft soils

Patricia Amo Sanz

Huesker Geosintéticos S.A.

HUESKER
Ideas. Ingenieros. Innovación.

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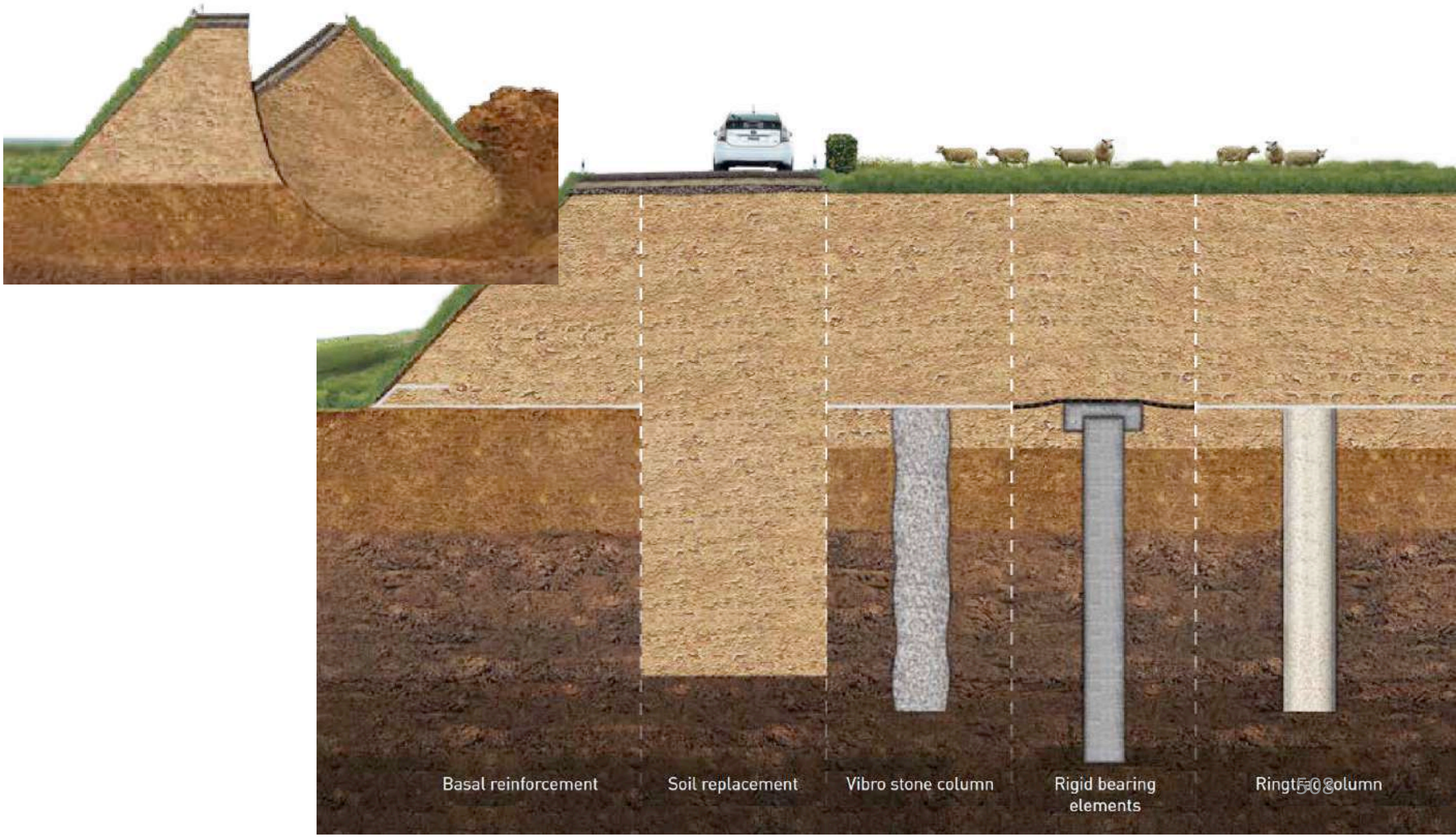
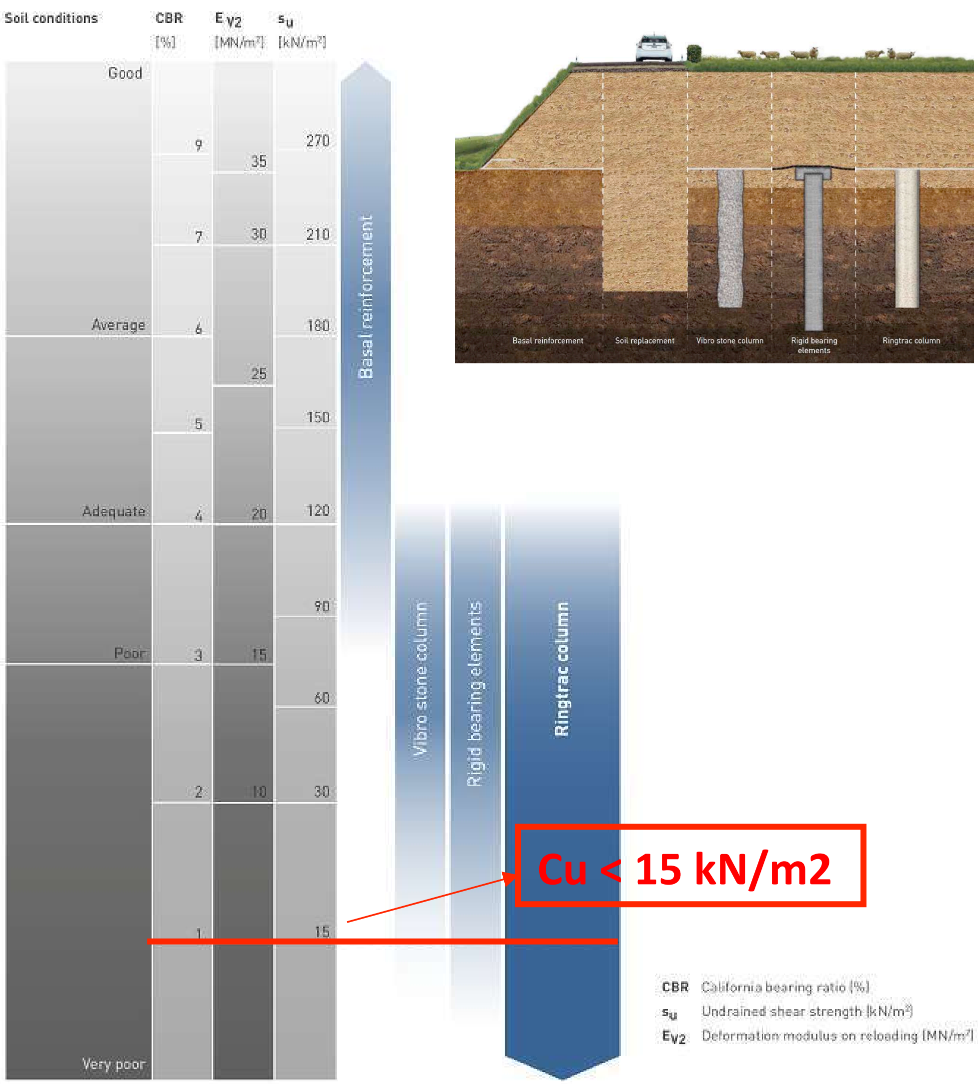
Apoios

- Methods of constructing embankment foundations to avoid the collapse of the structure built on soft soils

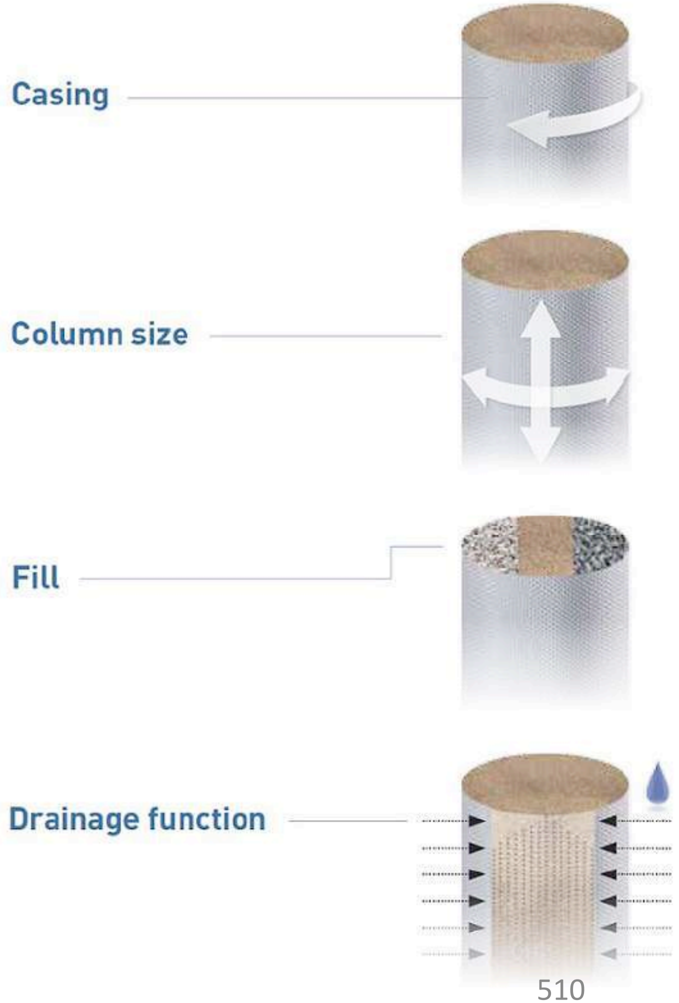


- Advantages of Ringtrac® as methods of constructing embankment foundations to avoid the collapse of the structure built on soft soils

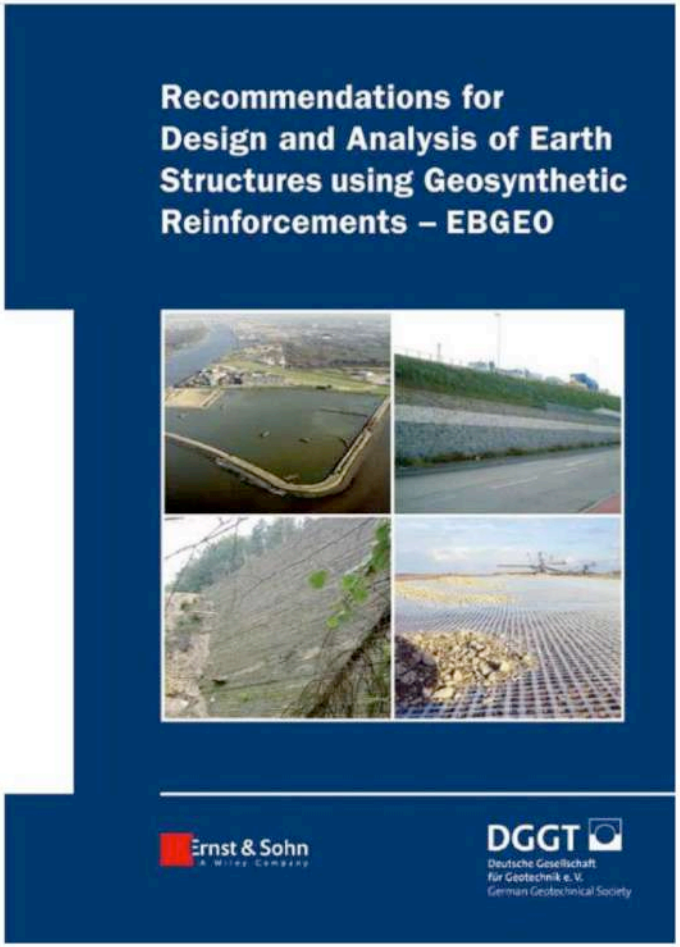


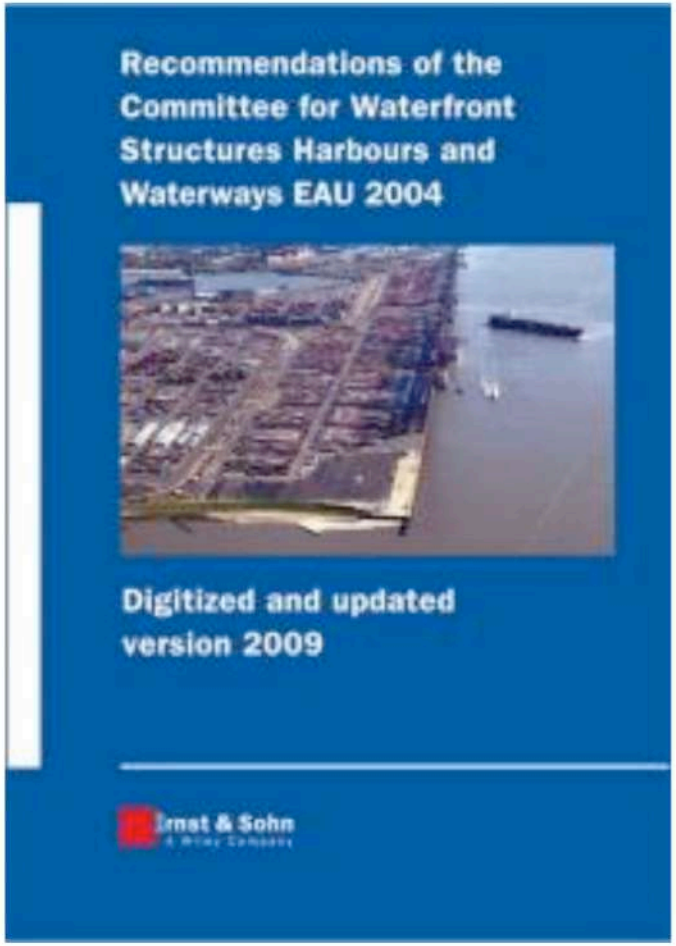
- Can be used in very soft soils (cu < 15 kN/m2). Also permissible under EBGEO for use in soils with Cu < 3 kN/m2
- Settlement reduction.
- Acceleration of settlements (vertical drainage effect → Megadrain). Around 90 % of consolidation is during construction period.
- Increase of shear strength.
- Flexible bearing behaviour.
- Geotextile is a filter and separation element.

- How the system works?

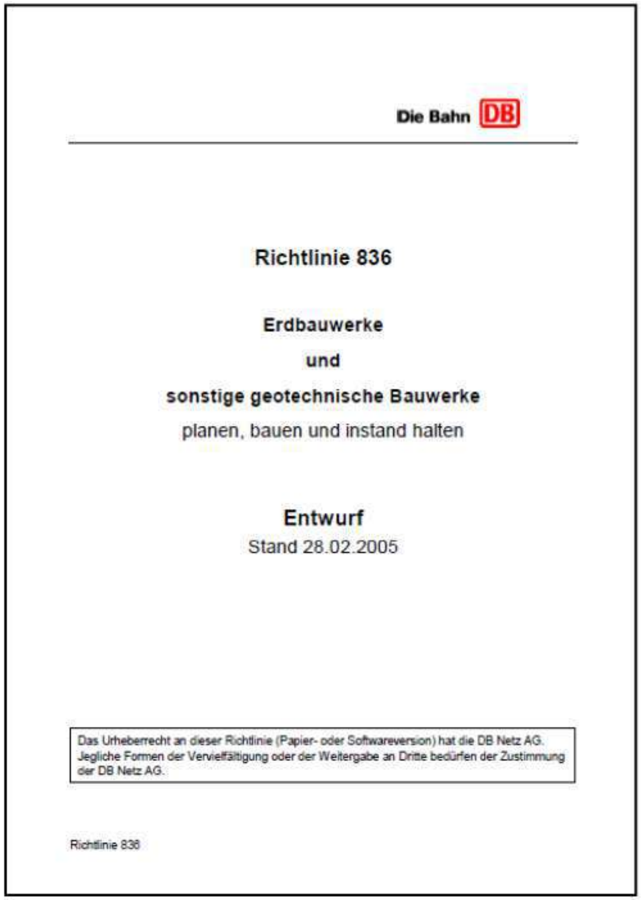


- Regulations for the GEC system in general and for German harbour and coastal construction in particular





- Regulations for the GEC system in German road and rail projects



Die Bahn DB

Richtlinie 836

Erdbauwerke

und

sonstige geotechnische Bauwerke

planen, bauen und instand halten

Entwurf

Stand 28.02.2005

Das Urheberrecht an dieser Richtlinie (Papier- oder Softwareversion) hat die DB Netz AG. Jegliche Formen der Vervielfältigung oder der Weitergabe an Dritte bedürfen der Zustimmung der DB Netz AG.

Richtlinie 836

Forschungsgesellschaft für Straßen- und Verkehrswesen

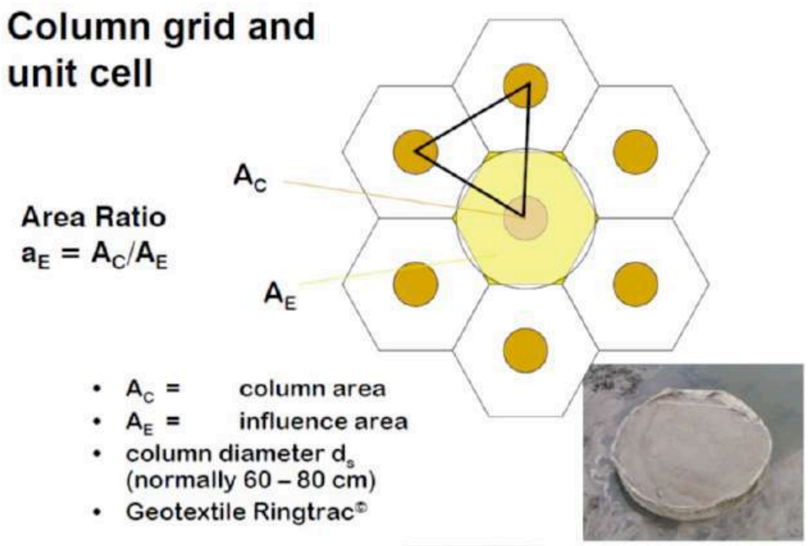
Arbeitsgruppe Erd- und Grundbau FGSV

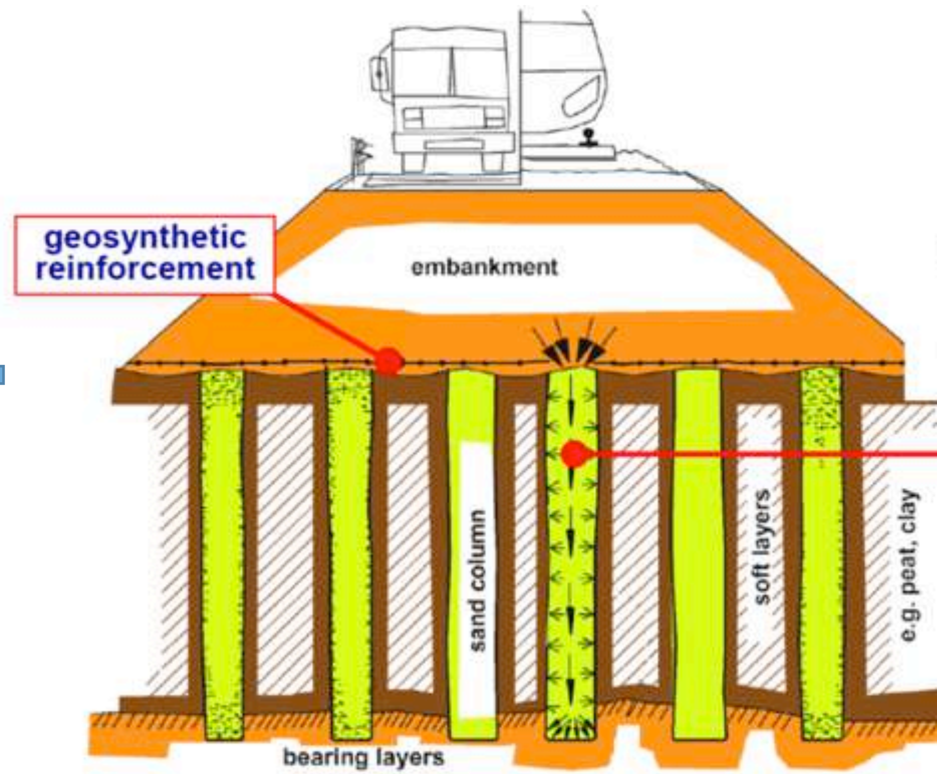
Merkblatt
über Straßenbau
auf wenig tragfähigem Untergrund

R 2

Ausgabe 2010

- How is the design?





Raithel

Global Stability

- Design with Raithel:

Following assumptions are made:

The settlements on the top of the column and the soft soil are equal.

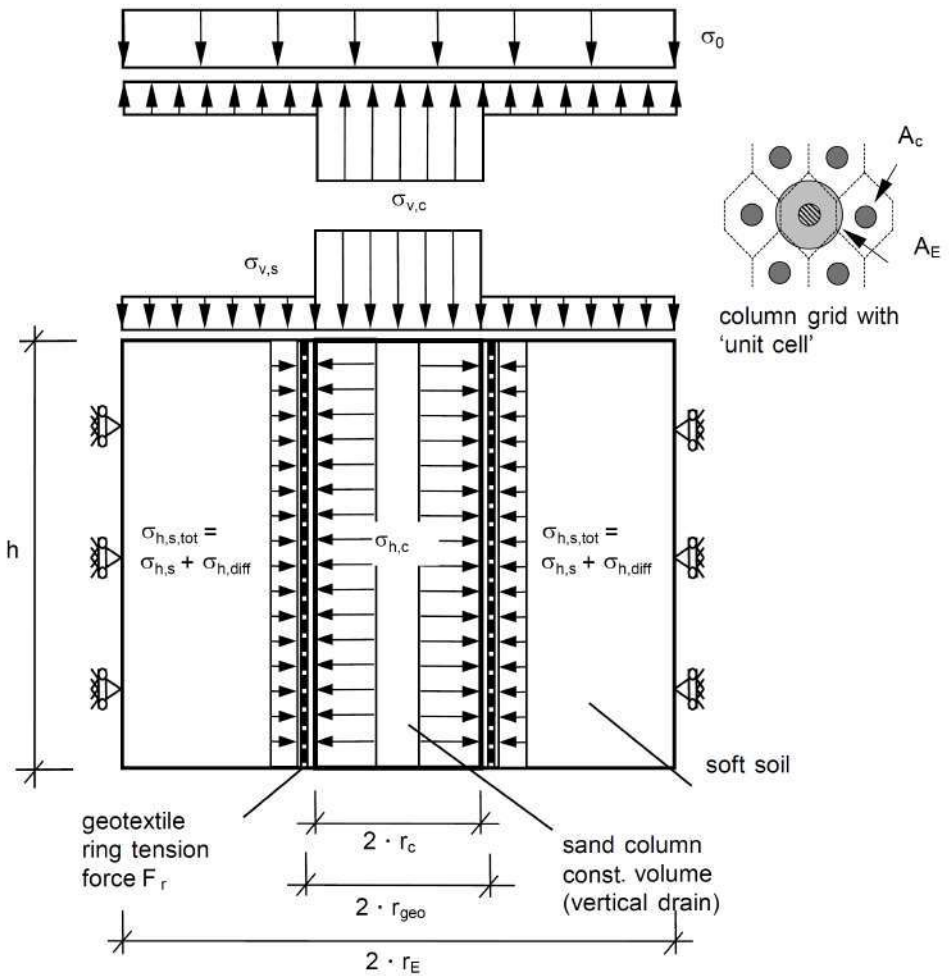
The settlements and strain in the geotextile result from the vertical pressure σ_0 in the column head area due to the loading.

The settlement of the bearing layer below the columns can be neglected.

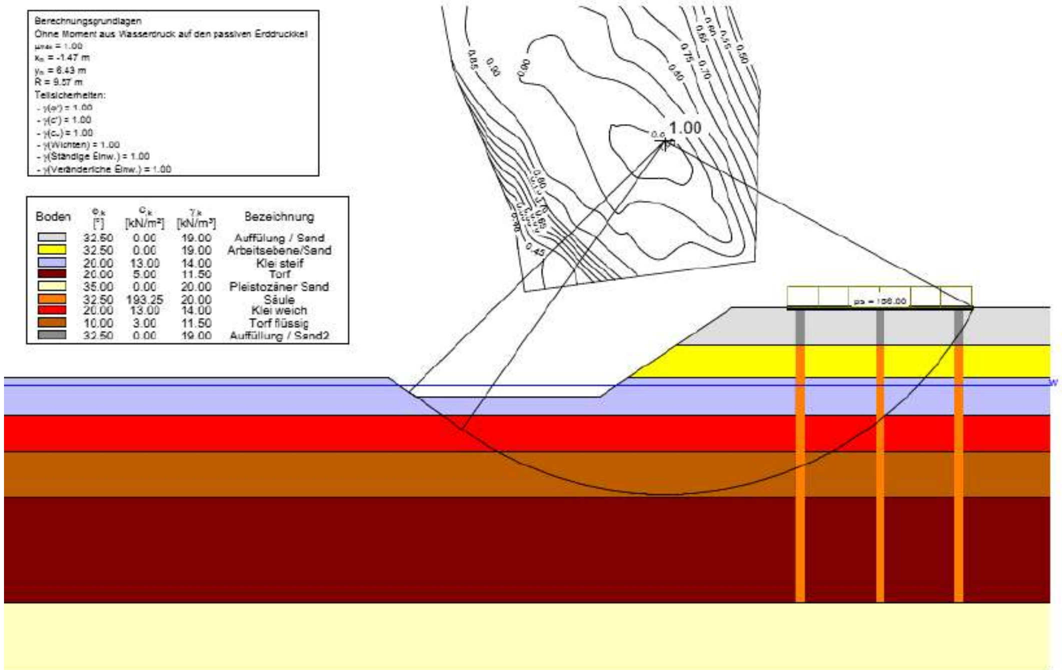
In column: the coefficient of active earth pressure is valid.

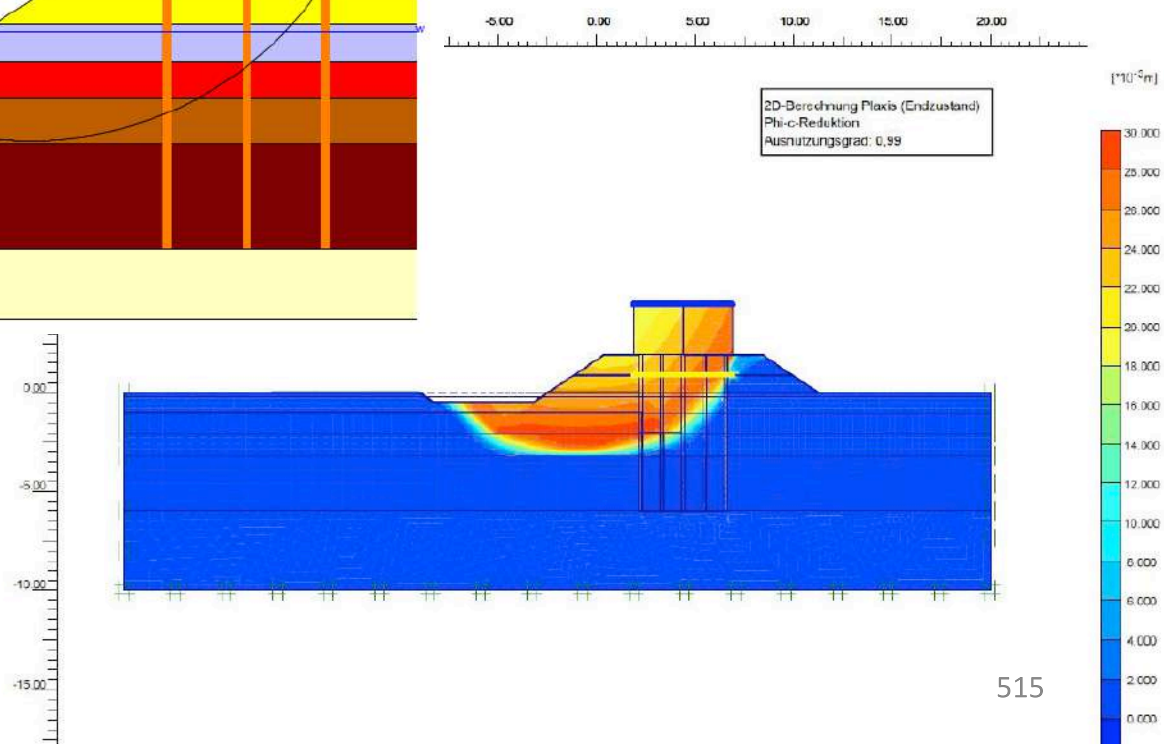
In soft soil after installation:
Using excavation method: the earth pressure at rest is valid.
Using displacement method: an enlarged coefficient of earth pressure $K_{0,B}^* \geq 1.0$ is given.

Geotextile Ringtrac has a linear-elastic material behaviour.



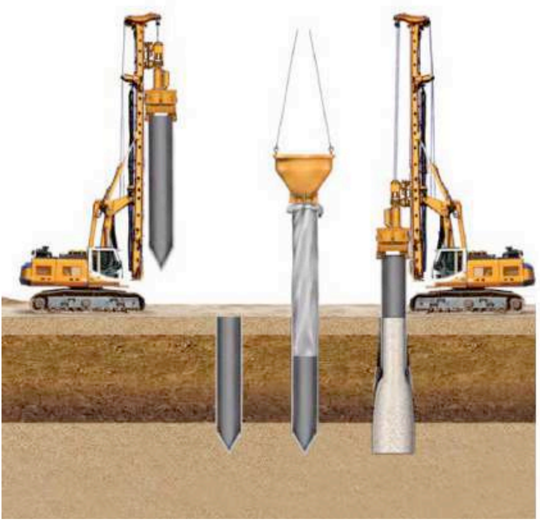
- Global stability with GGU analysis and PLAXIS



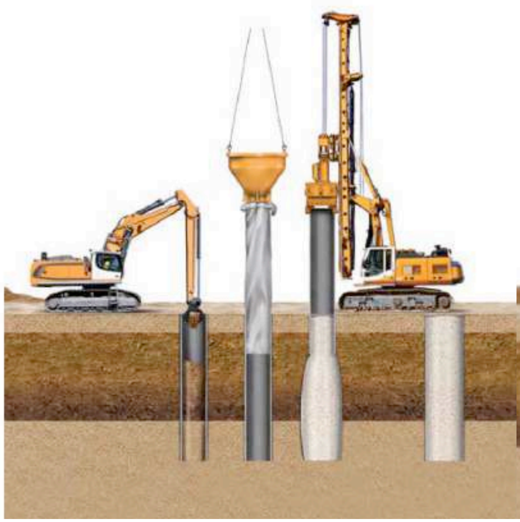


- Installation methods

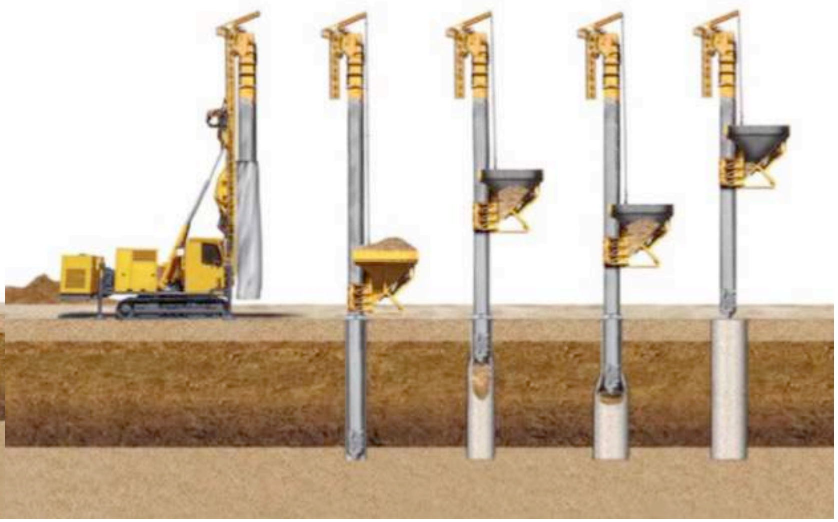
Displacement method



Replacement method



Vibro Displacement method



• Characteristics of column manufacturing methods

Table 10.1 Characteristics of column manufacturing methods

	Excavation method	Displacement methods	
		with casing	with deep vibrator
Possible manufactured diameter	More than 1.5 m	Generally up to 0.8 m	Generally up to 0.6 m
Removal and disposal of soil material	Necessary	Unnecessary	Unnecessary
Time required for column manufacture	More	Less	Less
Manufacture with very high penetration resistances[1)]	Possible	Generally not possible	Generally not possible
Vibrations and excess pore-water pressures as a result of column manufacture	Low	High[2)]	High[2)]
Column constriction during manufacture	No	Generally yes[2)]	Generally no[2)]
Horizontal and vertical displacement as a result of column manufacture	No	Yes[2)]	Yes[2)]
Prestressing of soft stratum during installation	No	Yes[2)]	Yes[2)]
Effects on geosynthetic casing during installation	Low	Low	Generally high
Examination of strata and column end depth	Possible visually	Via machine parameters	Via machine parameters

1) For example, dense intermediate sand layers
2) Depending on ground stiffness and grid spacing

- Conclusions

- Suitable for extremely soft soils.
- Almost all settlement takes place within construction period and reduce 50-75 % in creep settlement.
- Up to 50 % fewer columns than with vibro stone column solution.
- Adaptability to local conditions and loads.
- Use of locally sourced soils as columna fill.
- High level of certainty in costing and construction.
- Neighbouring structures shielded from horizontal presure + Adjacent buildings unaffected by settlement.


Thank you very much!!

Aplicação de tecnologia Geotube® no encapsulamento de solos contaminados em aterro: caso de obra marítimo-portuário de referência

Emanuel Ferreira
Geosin / TenCate

GEOSIN GEOSYNTHETICS
TENCATE GEOSYNTHETICS

Organização

Sociedade Portuguesa de Geotecnia

Comissão Portuguesa de Geotecnia nos Transportes

Comissão Portuguesa de Geossintéticos

Apoios

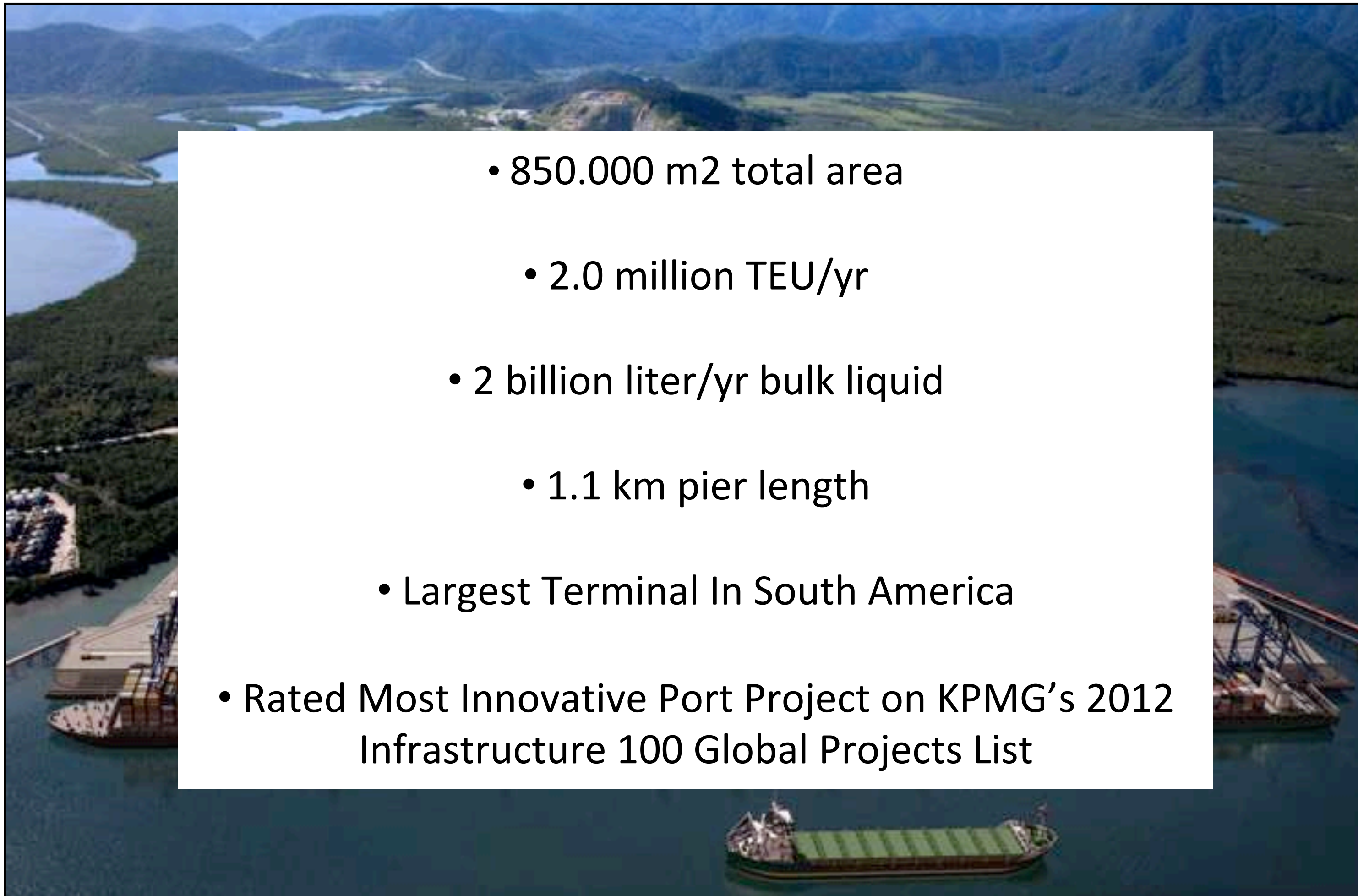
Embraport - Project Location

TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

The Project

The Project



- 850.000 m2 total area
- 2.0 million TEU/yr
- 2 billion liter/yr bulk liquid
- 1.1 km pier length
- Largest Terminal In South America
- Rated Most Innovative Port Project on KPMG’s 2012 Infrastructure 100 Global Projects List

The Challenge

- 50% of Project Area Located In Wetlands and Tidal Zone
- 600,000 m3 of Contaminated Sediments to be removed
- Required Large Volume of Imported Selected Fill
- Traditional Engineering Solutions threaten Economic Viability of Project

The Solution

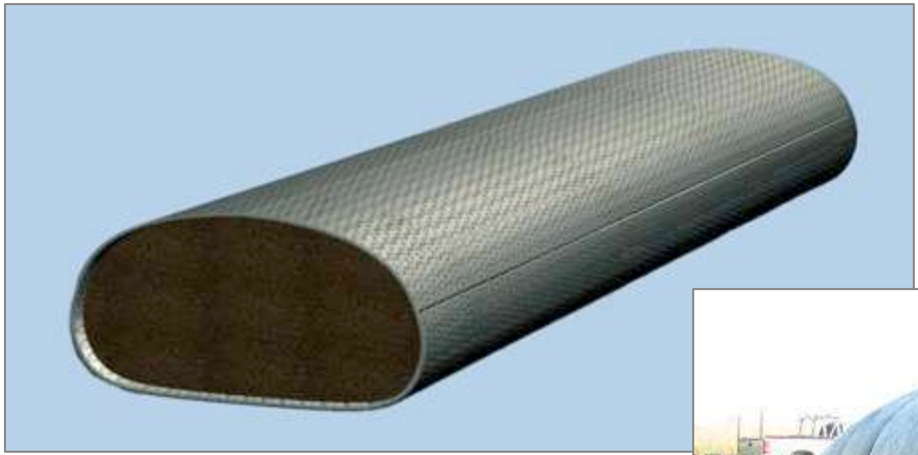
- Use Geotube Dewatering Technology to contain and dewater 600,000 m3 of contaminated sediments

- Create Geotube Dewatering Cells within the designed fill area

- Dredged Contaminated Sediments to be Contained, Dewatered and Consolidated within the Geotube Units, replacing approximately 450,000 m3 of imported select fill

- Create a Beneficial Use for the Contaminated Sediments and greatly reduce project construction cost

TenCate Geotube – Dewatering Technology



TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

TenCate Geotube – Dewatering Phases

TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

The Design

- Enclose the tidal flat area of the project with 3.5m high clay berms

- Construct Geotubes Dewatered Cells equal to 235,000 m2 within the tidal flat area of the project site

- Install 13,500 lm of 36.5m Cir. Geotube units with a storing capacity of 35.2m3/m in the Dewatering Cells

- Dredged Contaminated Sediments into Geotubes Units, to be Dewatered and Consolidated to at least 450,000 m3 to replace imported select fill

Geotube® Simulator
Cross Section

1/17/10	**Project:**	**Embraport Geotube Cross Section**

Units:	Metric		Circumferential Tensile Force (T) =	16.96	kN/m
Water Level:	Fully Emerged		Geotube® Base Contact Width (B) =	15.84	m
			Geotube® Filled Width (W) =	17.24	m
Geotube® Height (H) =	2.2	m	Geotube® Cross Section Area (A) =	35.21	sq m
Geotube® Circumference (C) =	36.5	m	Geotube® Volume Per Unit of Length (V) =	35.21	cu m/m
Relative Density of Fill Material =	1.4	sg	FS of Circumferential Failure =	4.6	FS
Geotube® Fabric Type:	GT500		Axial Direction FS (AFS) =	4.4	FS
Geotube® Fabric Type:	Rigid Mechanical		FS of Fill Port Failure =	4.7	FS

TENCATE Geotube

Geotube® Estimator

Metric Units Input - Known Volume

Version 11.2A

Tom Stephens

Project Name:	Embraport Terminal
Location:	Santos, SP, Brazil
Contact:	Luiz Escobar, Leo Melo Casar
Date:	5/6/2007
Type of Material:	Marine Sedimants

Input		Units
Volume	680,000	Cubic Meters
Specific Gravity	2.65	
% Solids in Place	40.0%	
% Solids During Pumping	10.0%	
Target dewatered % Solids	63%	
% Coarse grain & sand*	20.0%	

* % Coarse grain & sand is removed from the calculation for volume reduction due to dewatering and added back in at the end in required Geotube® volume.

Production:

Pumping Rate (LPM)	10,000
Hours per Day	24.0
% Efficiency	60%

Material type:

Sand and/or Minerals

Percent of Maximum Filled Capacity

90%

For MDS Applications:

Legal Hauling Capacity	14	Tons

Output		Units
Total Volume Pumped	3,397,016,508	Liters
Wet Volume per day	8,639,994	Liters
Wet Volume per day	8,638.9	CM
Total Bone Dry Tons	289,639.0	Tons (metric)
Estimated Pumping Days	393.2	Days
Estimated Dewatered Volume	415,528.3	CM
Estimated Dewatered Weight	731,744.6	Tons (metric)

Estimated Geotube® Quantity:

Circumference X Pumping Height	*Meters*	
9.15m X 1.52m	93,433	
13.72m X 1.67m	51,995	
18.29m X 1.83m	34,276	
22.87m X 1.98m	24,640	
24.39m X 1.98m	22,836	
27.44m X 1.98m	19,920	
36.56m X 2.13m	13,425	
22.87m X 1.98m	24,640	Selectable

Estimated MDS Geotube® Units:

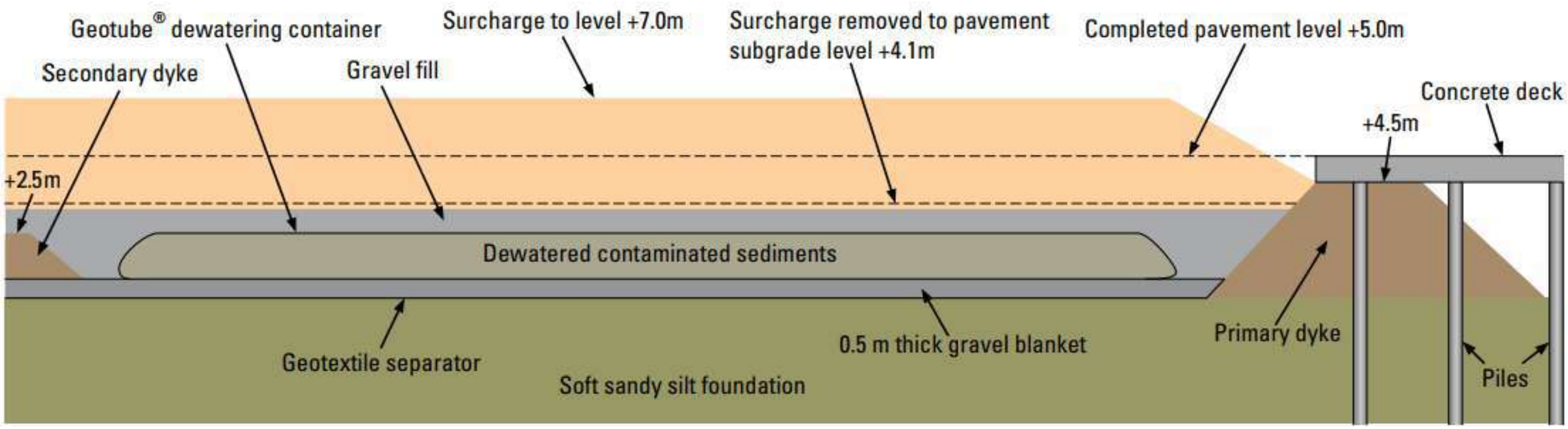
MDS Dimensions	*Each*
6.86m X 6.7m	59,276.0

Disclaimer: No warranty or guarantee expressed or implied is made regarding the performance of any product since the manner of handling and use is beyond our control. This document should not be construed as engineering advice, and the final design should be the responsibility of the project engineer and/or the project manager.

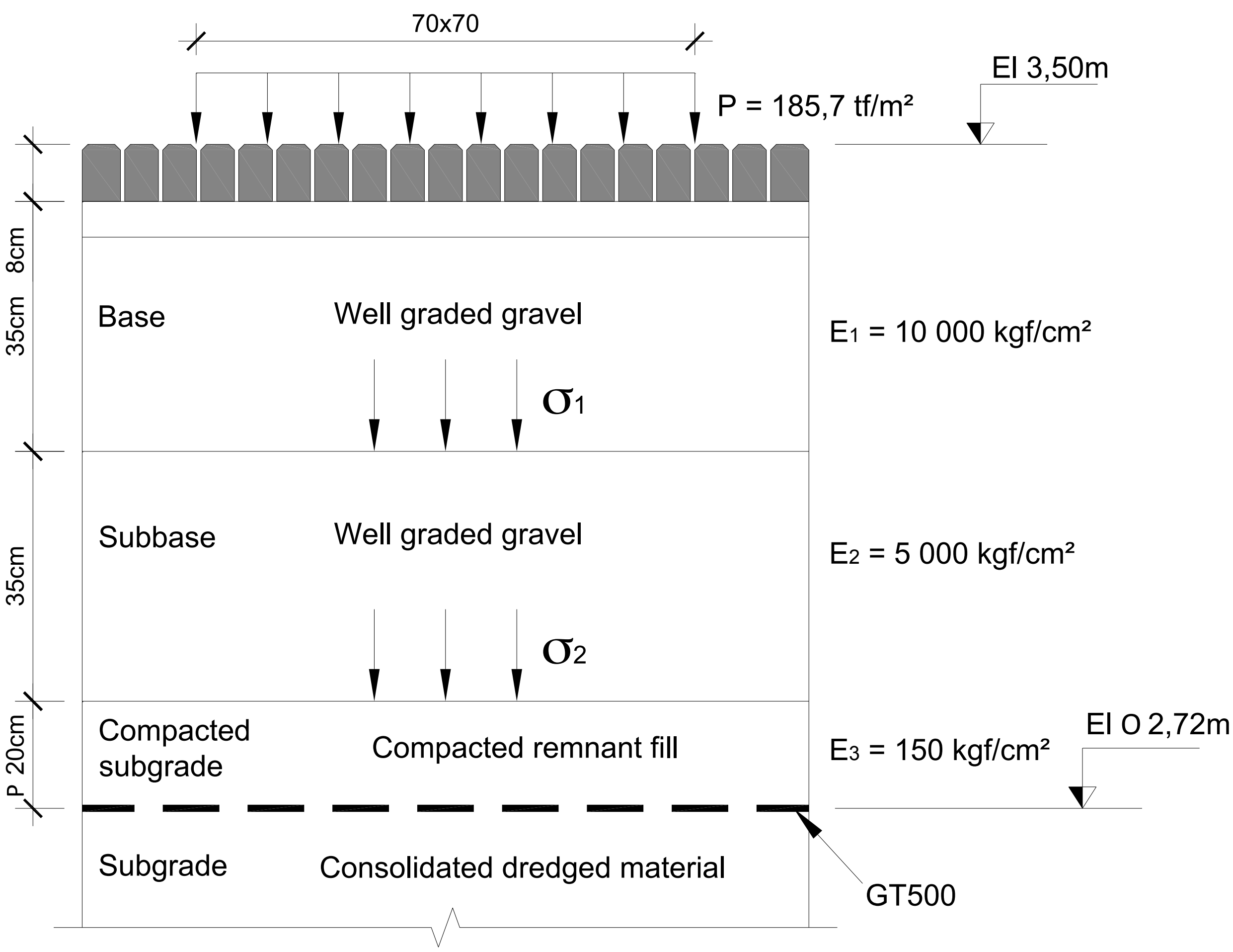
TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

The Design


Geotube® dewatering container
Surcharge to level +7.0m
Surcharge removed to pavement subgrade level +4.1m
Completed pavement level +5.0m
Secondary dyke
Gravel fill
Concrete deck
+4.5m
+2.5m
Dewatered contaminated sediments
Primary dyke
0.5 m thick gravel blanket
Geotextile separator
Soft sandy silt foundation
Piles

The Design



TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

The Pavement Design

For verification, the gravel has no cohesion, therefore c = 0, and the footing is at surface level, therefore D = 0 and q = 0 which simplifies the formula to

Solve for the Allowable Bearing Capacity,

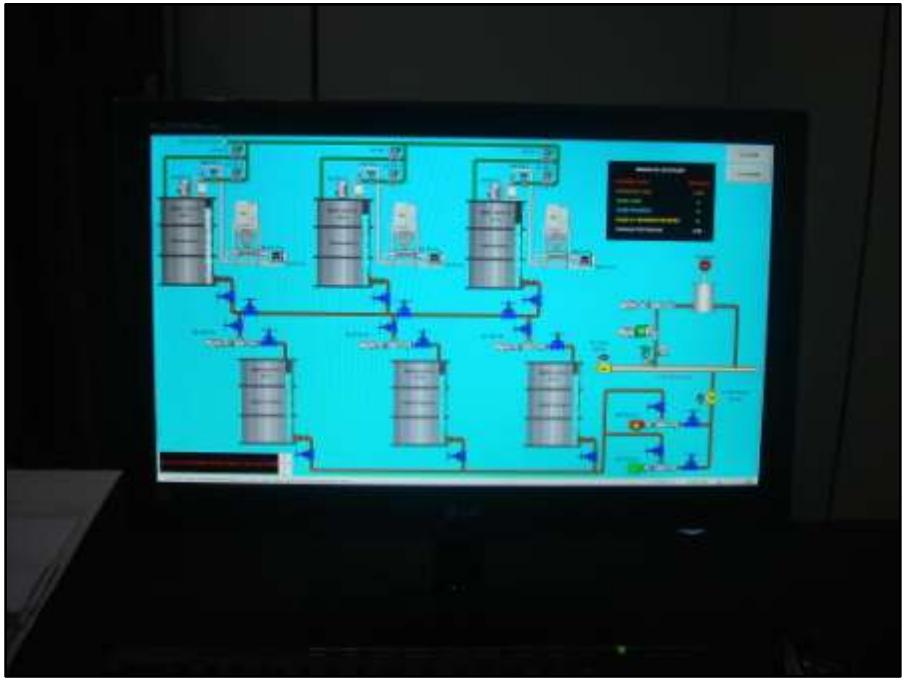
where B = 0,7m, γ = 2,1T/m², Sγ = 0,8 for a square footing as indicated by Terzaghi and Nγ = 763 for φ = 50º, giving:

$$q_u = 0{,}8 \times 2{,}1 \times 0{,}7 \times 763/2 = 448{,}6 (T/m^2)$$

which leads to the safety factor:

Bearing Capacity FS = (448.6 / 185.7) = 2.42

The Dewatering Operation



The Dewatering Operation

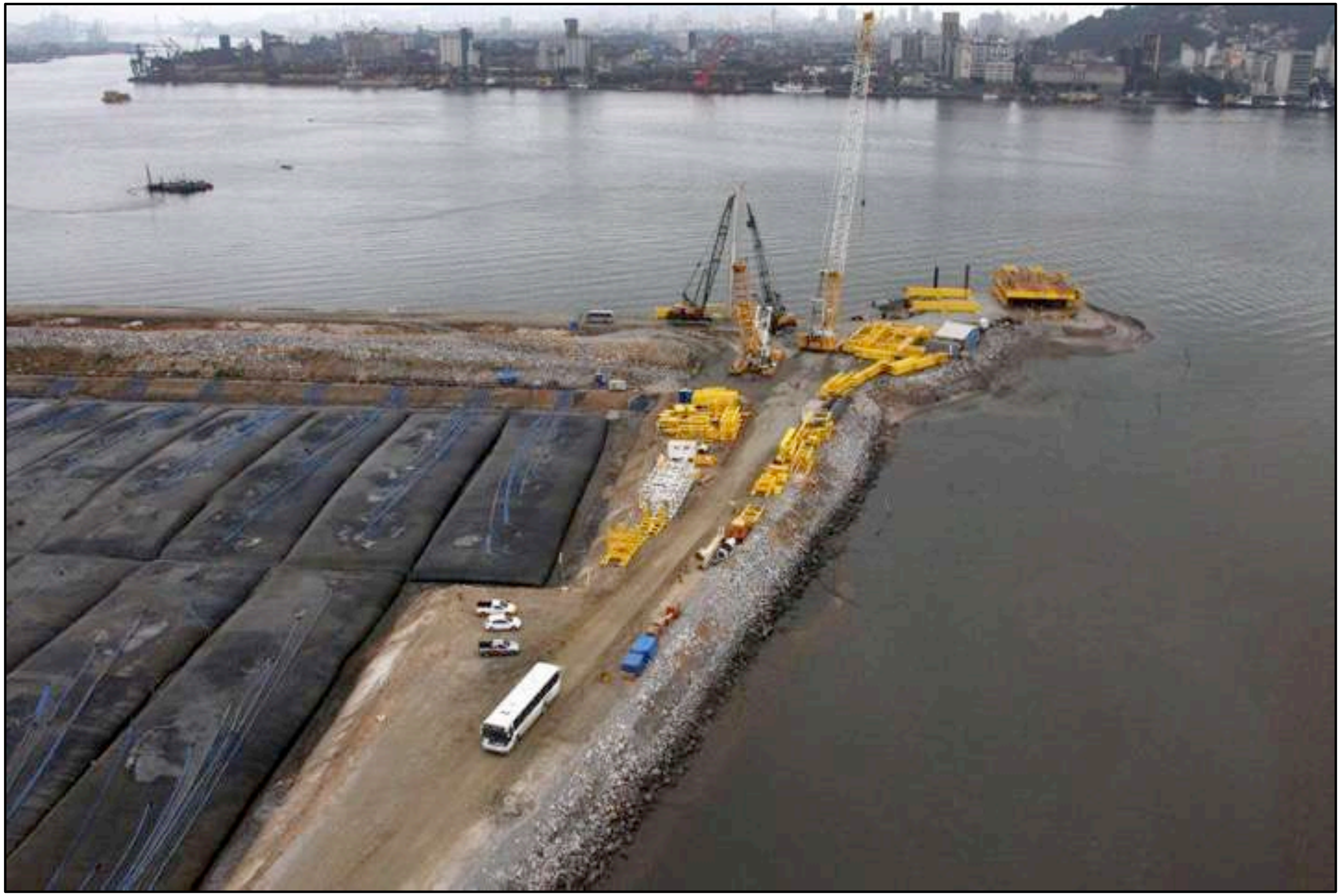
The Dewatering Operation

The Dewatering Operation

TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

The Dewatering Operation



The Construction

The Construction

The Construction

The Construction

The Construction

The Construction

The Construction

Questions are welcome!

Thank you for your interest!

Presented by:

Emanuel Ferreira

Co- Authors:

Filinto Oliveira

Gerben van den Berg

TENCATE GEOSYNTHETICS

GEOSIN GEOSYNTHETICS

THE USE OF 16 TON CDC COMPACTION FOR THE GROUND IMPROVEMENT OF THE TRANSPORTATION ROUTE OF A 13.500 TON RAILWAY BRIDGE (NL)

J.W. Dijkstra M.Sc.
Cofra

Organização
Sociedade Portuguesa de Geotecnia
Comissão Portuguesa de Geotecnia nos Transportes
Comissão Portuguesa de Geossintéticos
vfx Ligações Fortes
Câmara Municipal

Apoios
LNEC Laboratório Nacional de Engenharia Civil
Ordem dos Engenheiros

Index

- Project overview
- Specific case
- Chosen method
- Challenges
- Results

Main Project

- SAA (Schiphol-Amsterdam-Almere)
- SAA-One (number 2 on the map)
- Widening of the A1 highway
- Main highway >200.000 cars/day
- Construction of new railway bridge

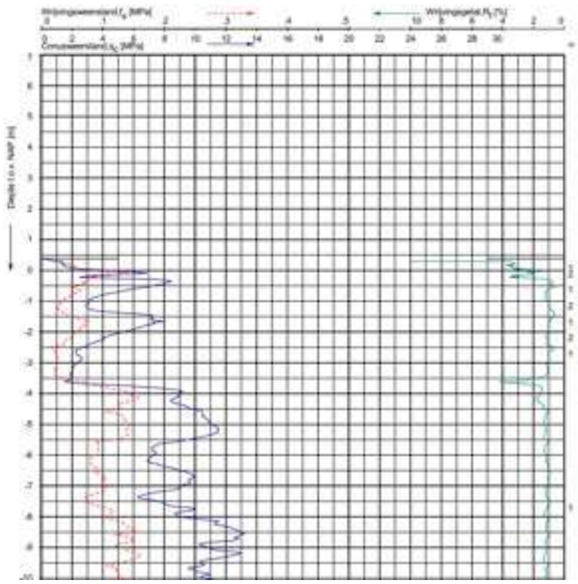
Bridge location

Bridge and route details

- Free span of 255m (Eiffel tower is 324m), height 50m
- Weight of 13.500 ton (almost two times the steel weight of the Eiffel tower)
- 140 kN uniform loading of SPMT
- Path of the bridge 380m

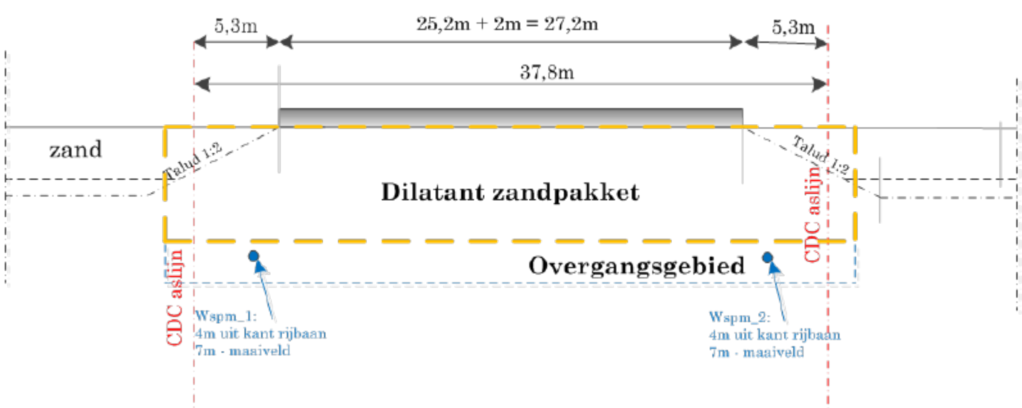
Soil conditions

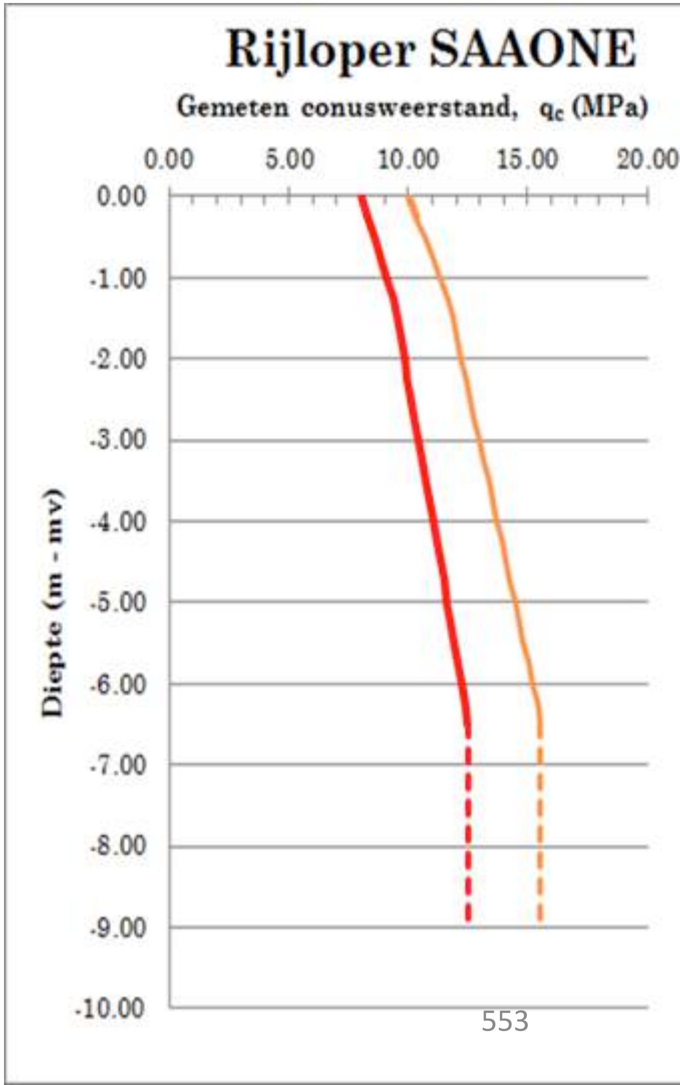
- Up to 4m peat on top of thick sand body
- Very loose sections of sand in top layers underneath the existing highway



Requirements

- Have a dilatant behavior of the sand and prevent static liquefaction under the sudden loading
- Target ~85% RD over top 6.5m (orange)
- Minimum is 80% RD on limited stretches (red)





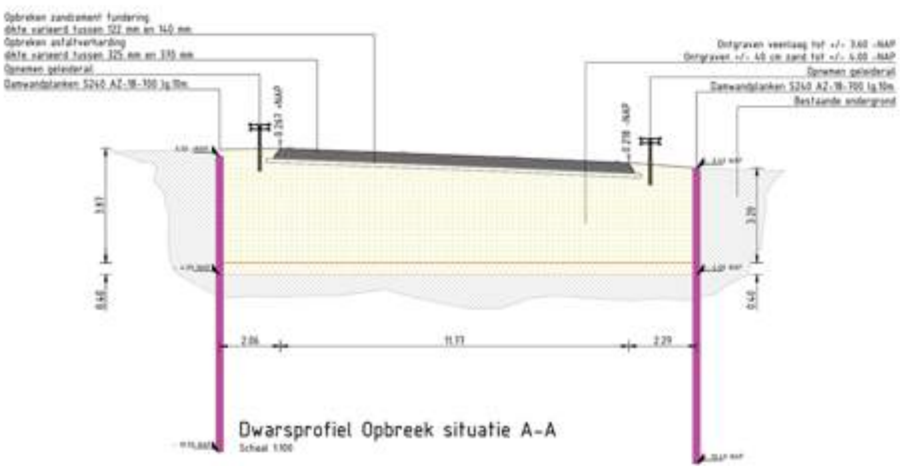
Boundary conditions highway

- Only weekend closures possible for improvement of highway
  - Removal of asphalt
  - Perform solution
  - Solution needs to be suitable to be performed 3m from moving traffic
  - Make subbase
  - Install pavement
  - Install markings

  - Time slot of 8 to 12 hours for ground improvement and testing !!

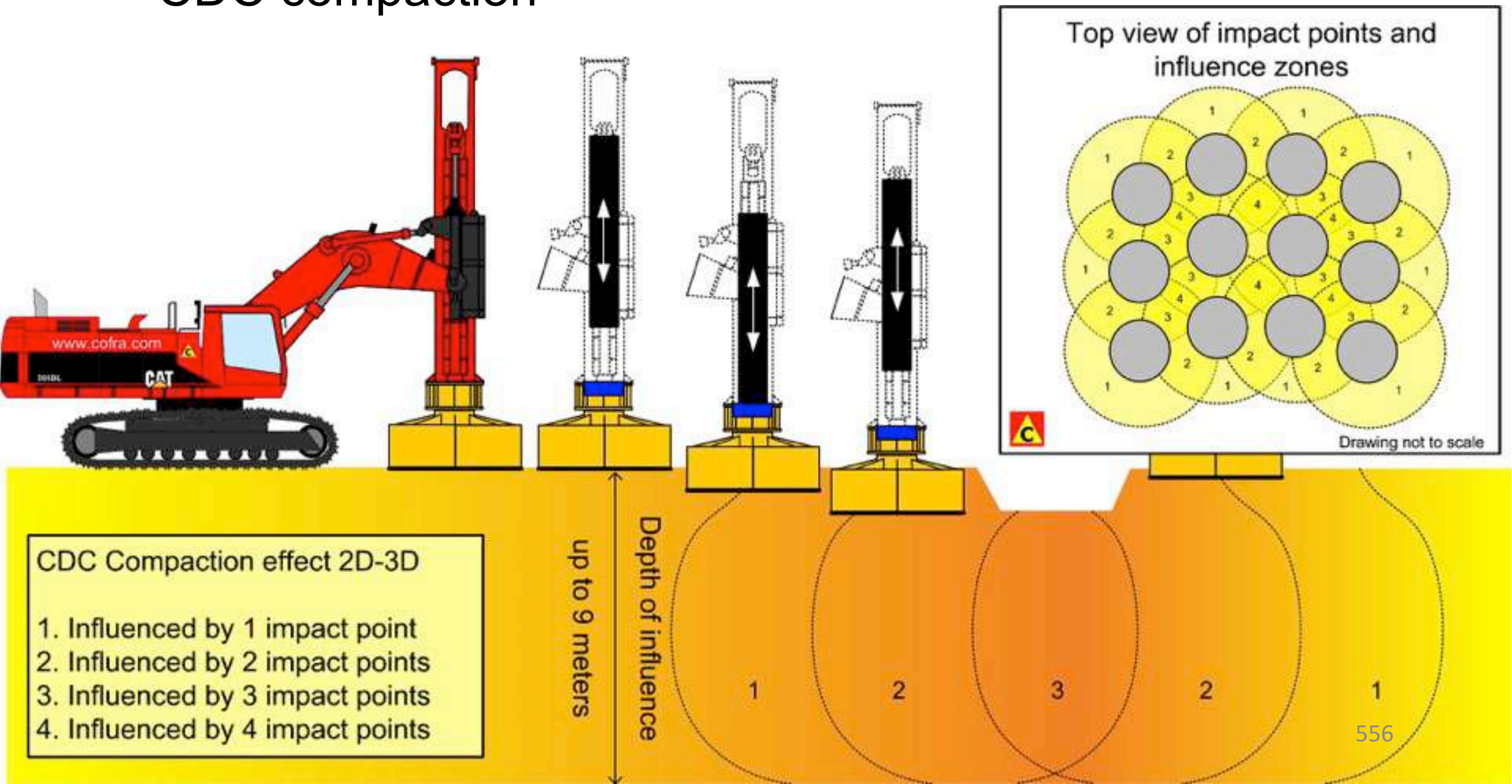
Ground improvement solution

- Compaction of highway sections with CDC
- Soil replacement with CDC compaction on other sections
  (sand available from surcharge of PVD improved main stretch of highway)



Compaction method

- CDC compaction



Compaction method

- Small video

Impression

Working alongside highway

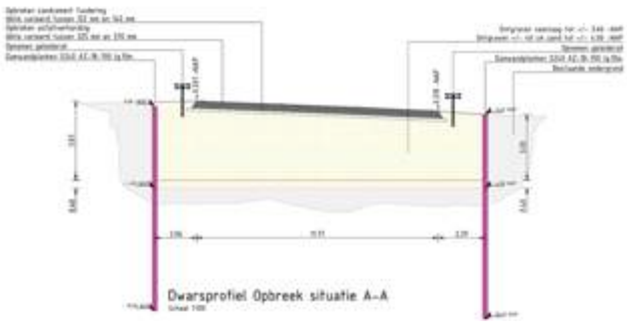
Timelaps

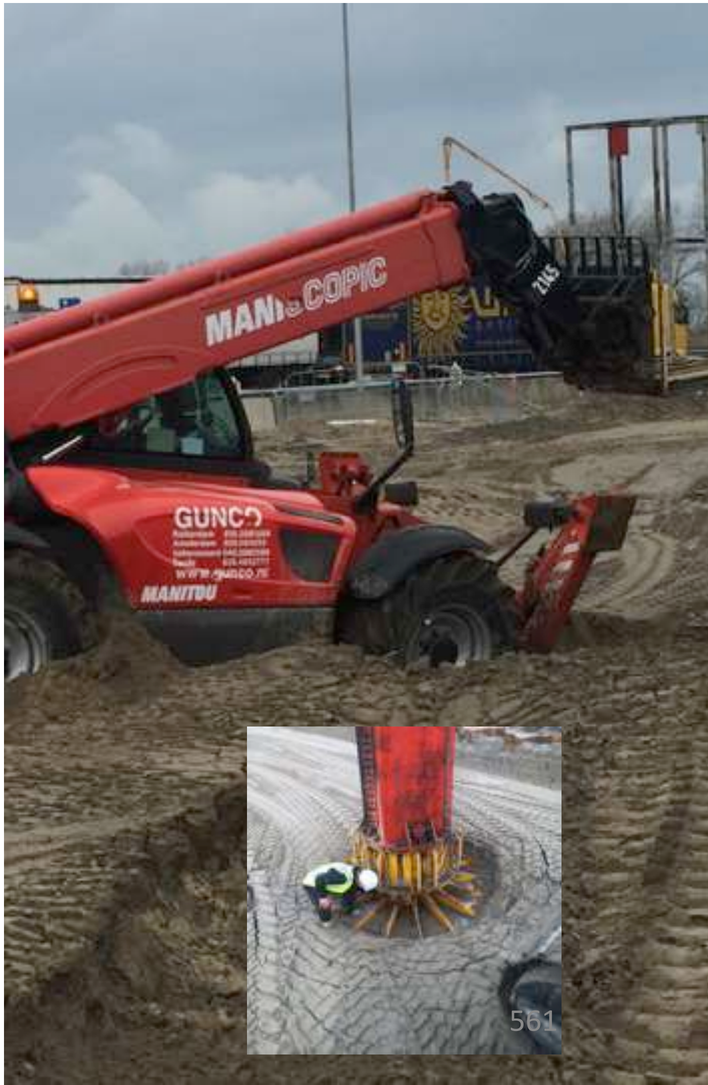
Challenge: Loose sand

- Very loose condition backfilled sand combined with high water table
- Shoebox – no drainage to the sides

Resulting in:

- Stability issues
- Compaction less effective





Solution: Dissipation of porewater

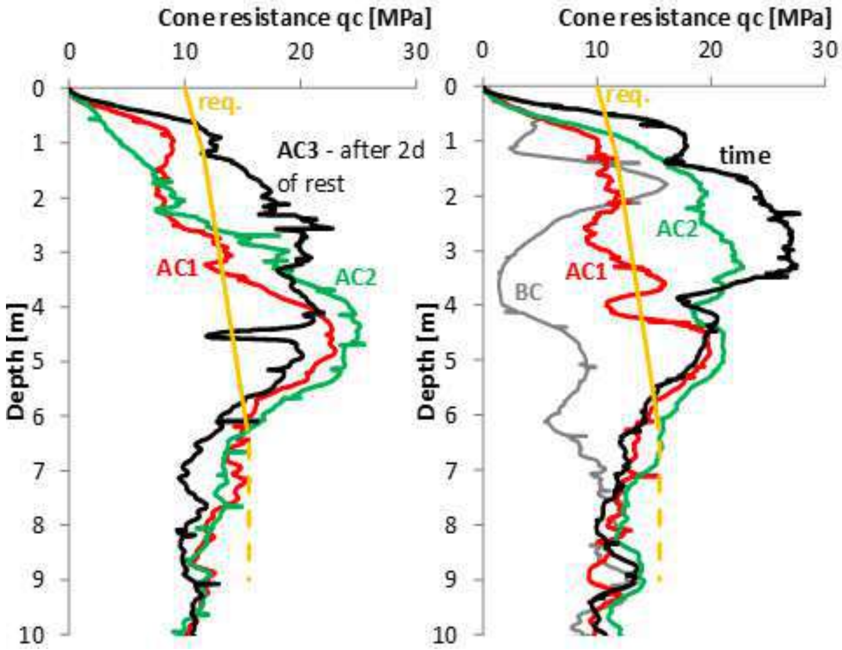
- Adjusted work method
- Installation of PVD

Challenge: Time

- Immediate CPT testing after compaction

Resulting in:

- Cone resistance line is influenced, limited effect (?).

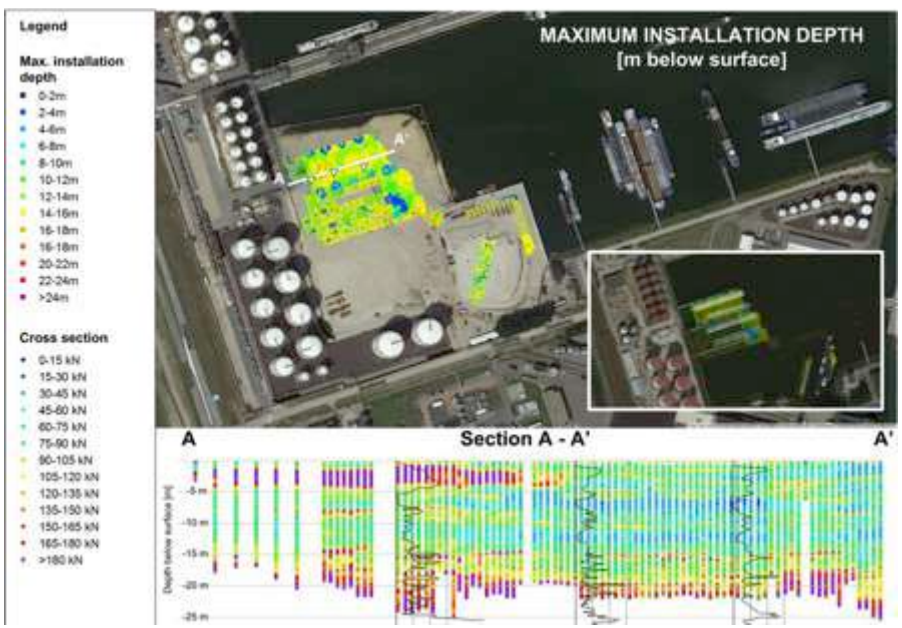


Solution: GPS quality control

- GPS based positioning and registration of data

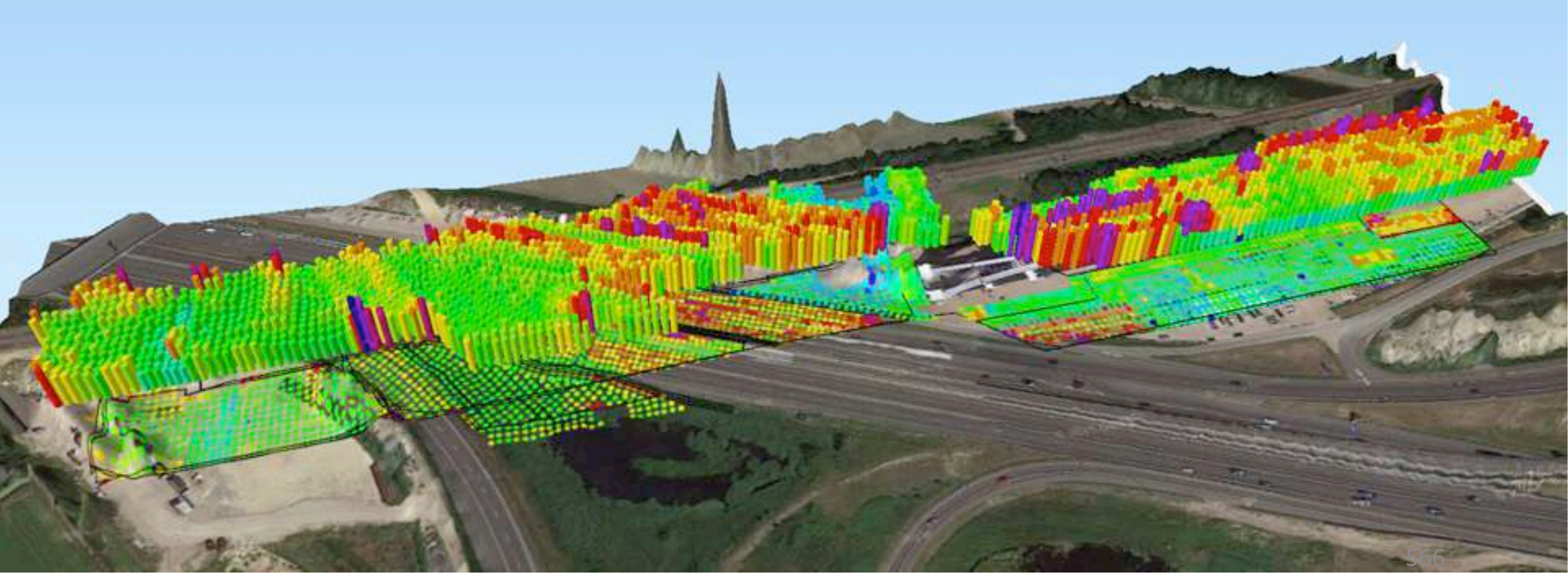
Our GPS quality control

- Used on all our techniques
  - Consolidation (PVD, vacuum)
  - Compaction (Roller, CDC en Vibro)
  - Elements (GEC, stone columns, piles)



GPS quality control CDC

- Settlement
- Blows
- Settlement per blow



GPS quality control CDC

- Settlement
- Blows
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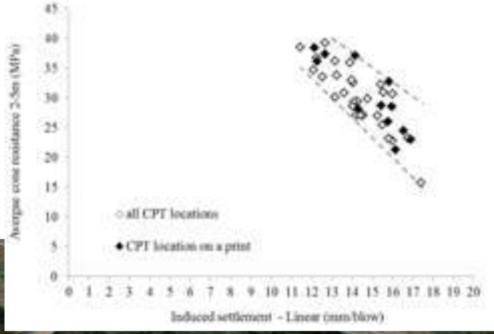
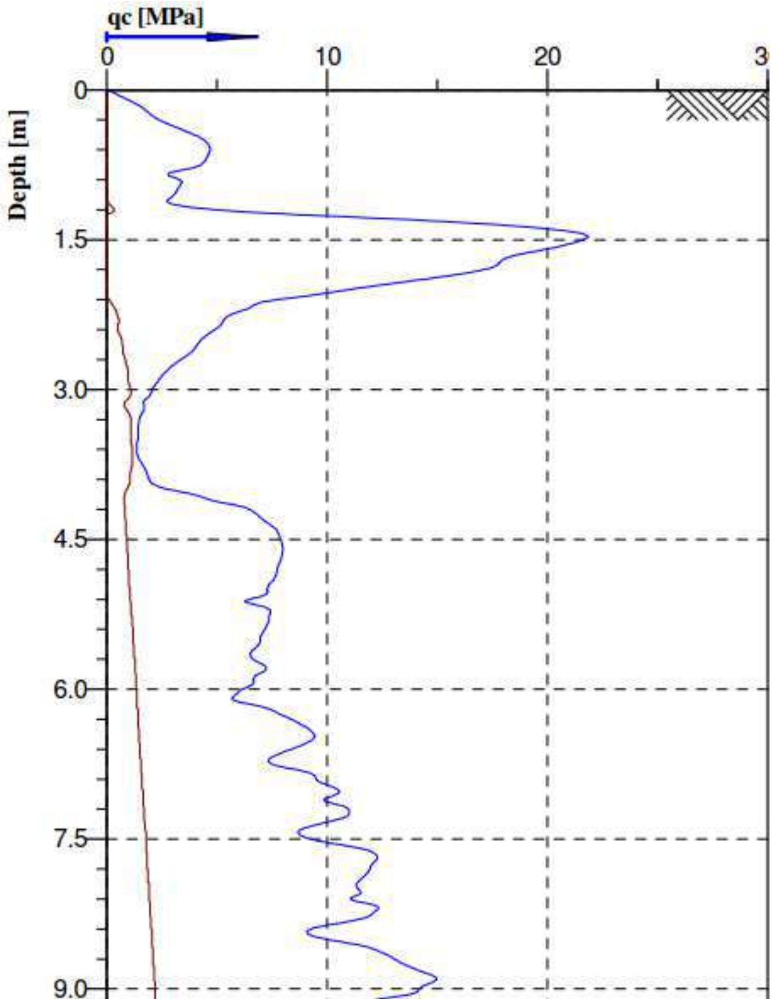
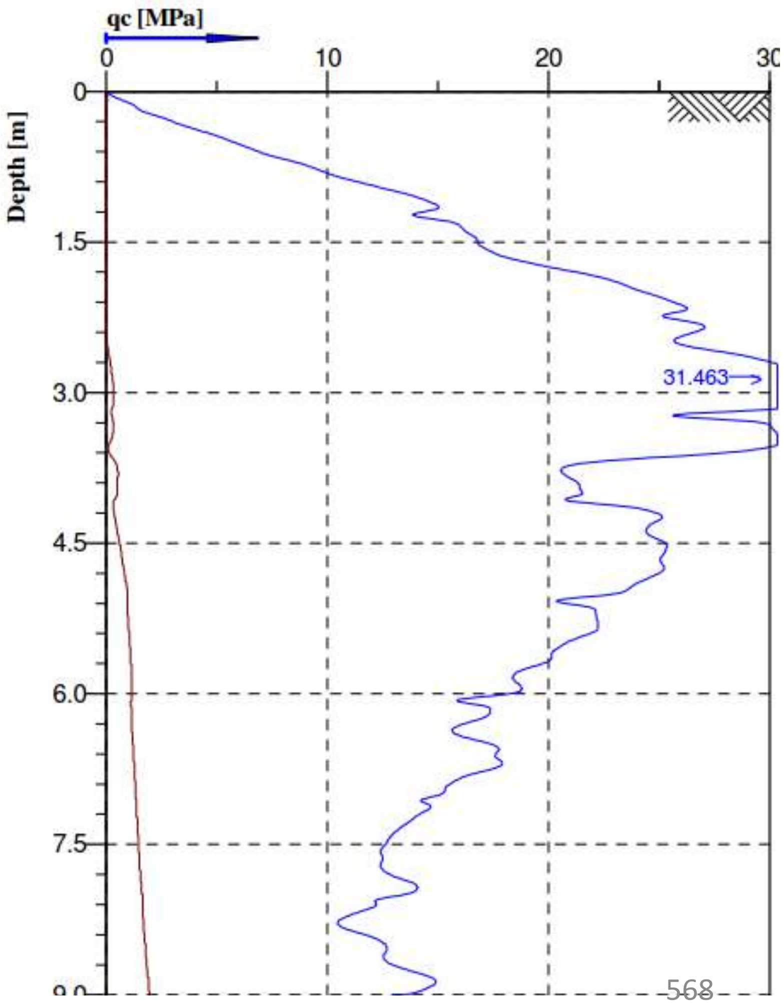
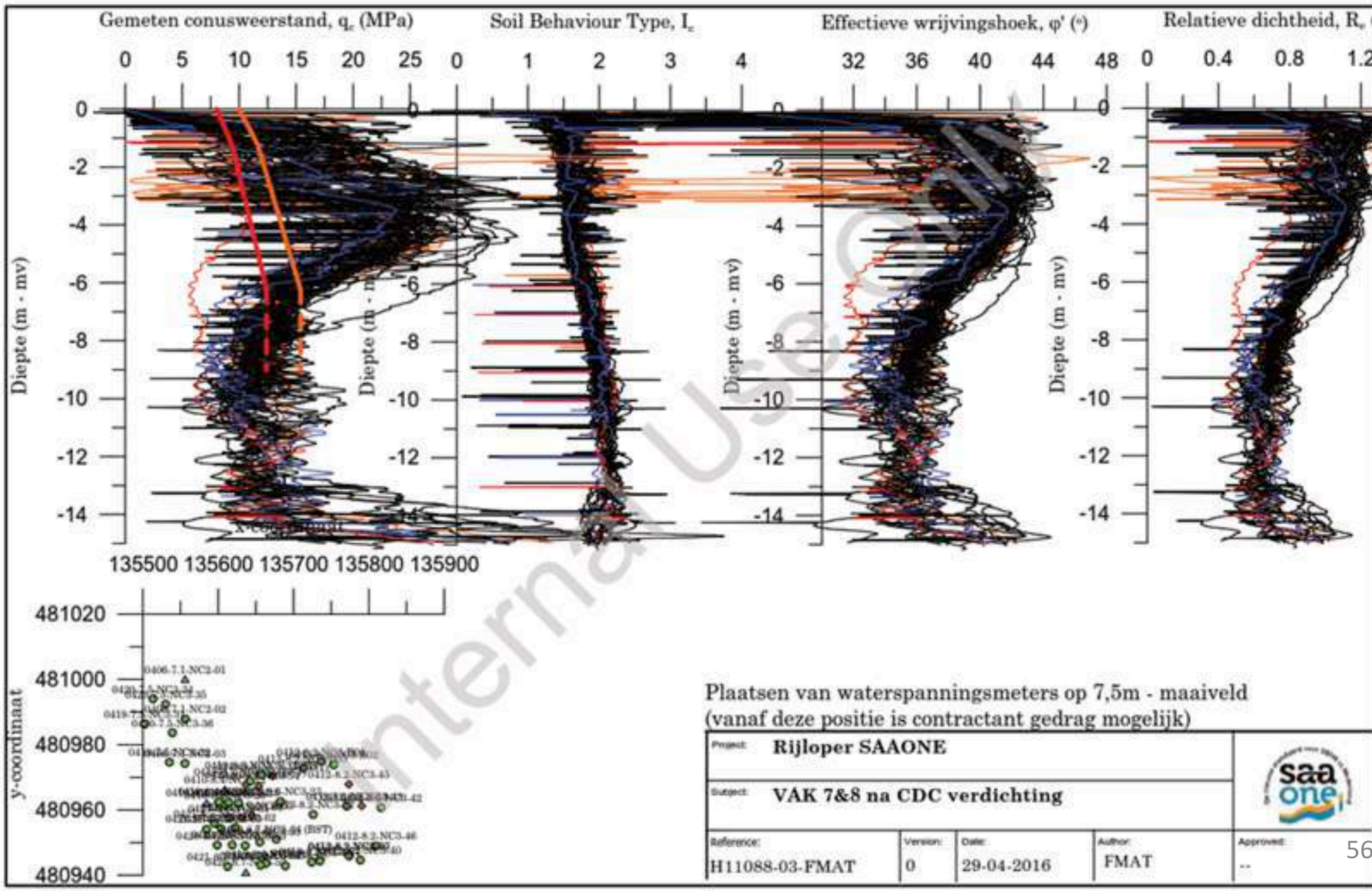


End results CPT

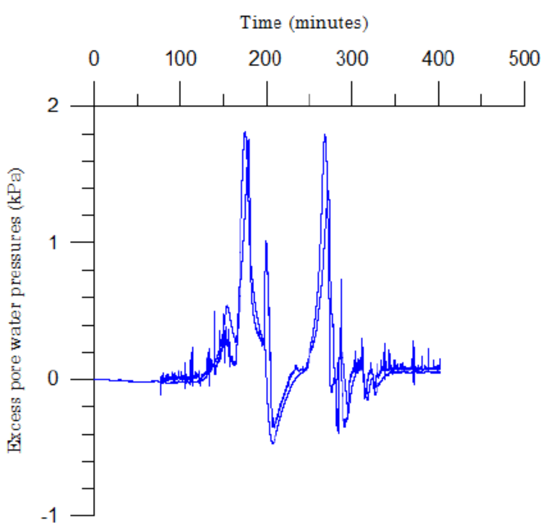




End results CPT



End results: Dilatancy



Obrigado!

Reinforcement and Ground Improvement GEOPIER® Solutions

Javier Moreno
TERRATEST, S.A.

GRUPO TERRATEST

Organização

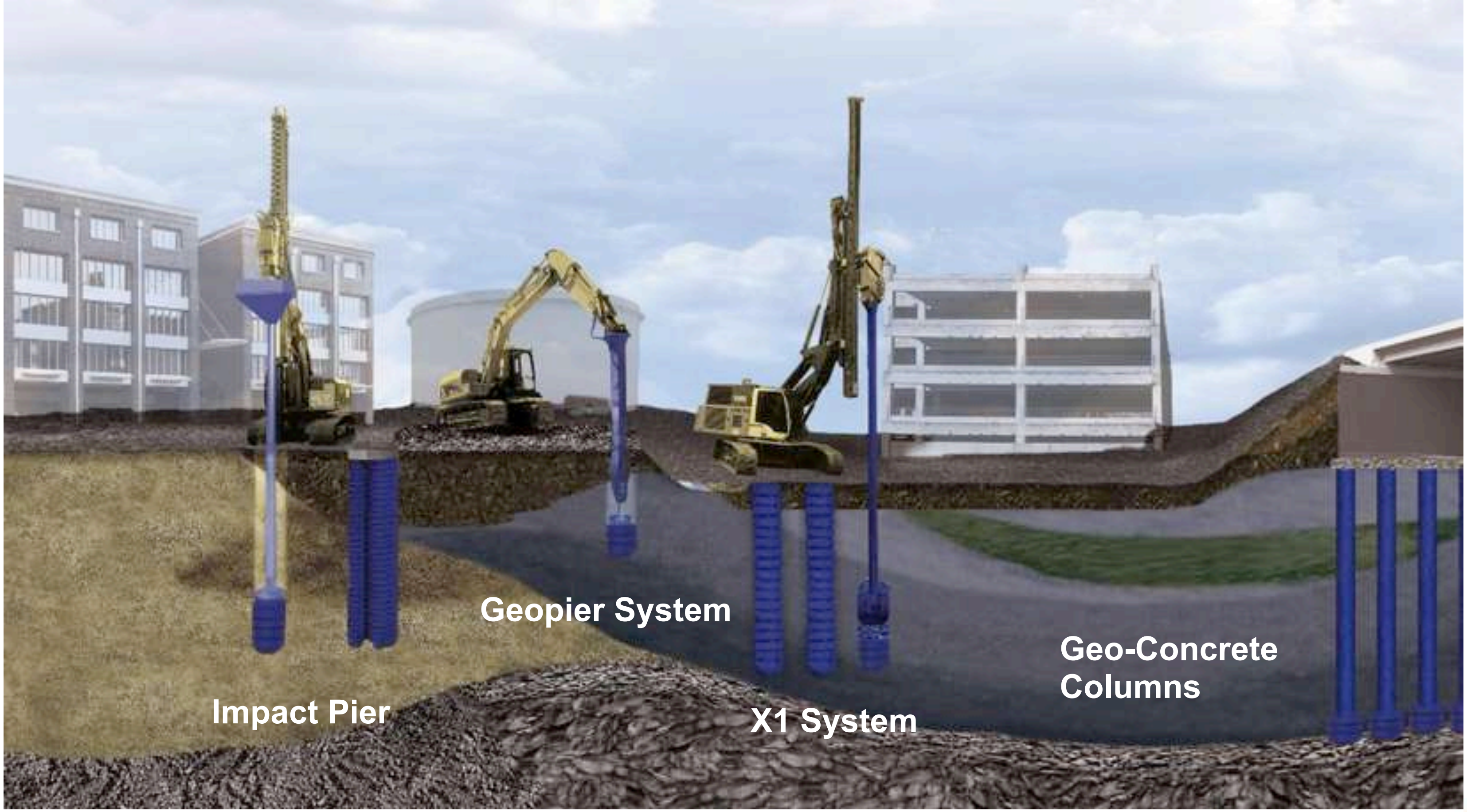
Sociedade Portuguesa de Geotecnia

Comissão Portuguesa de Geotecnia nos Transportes

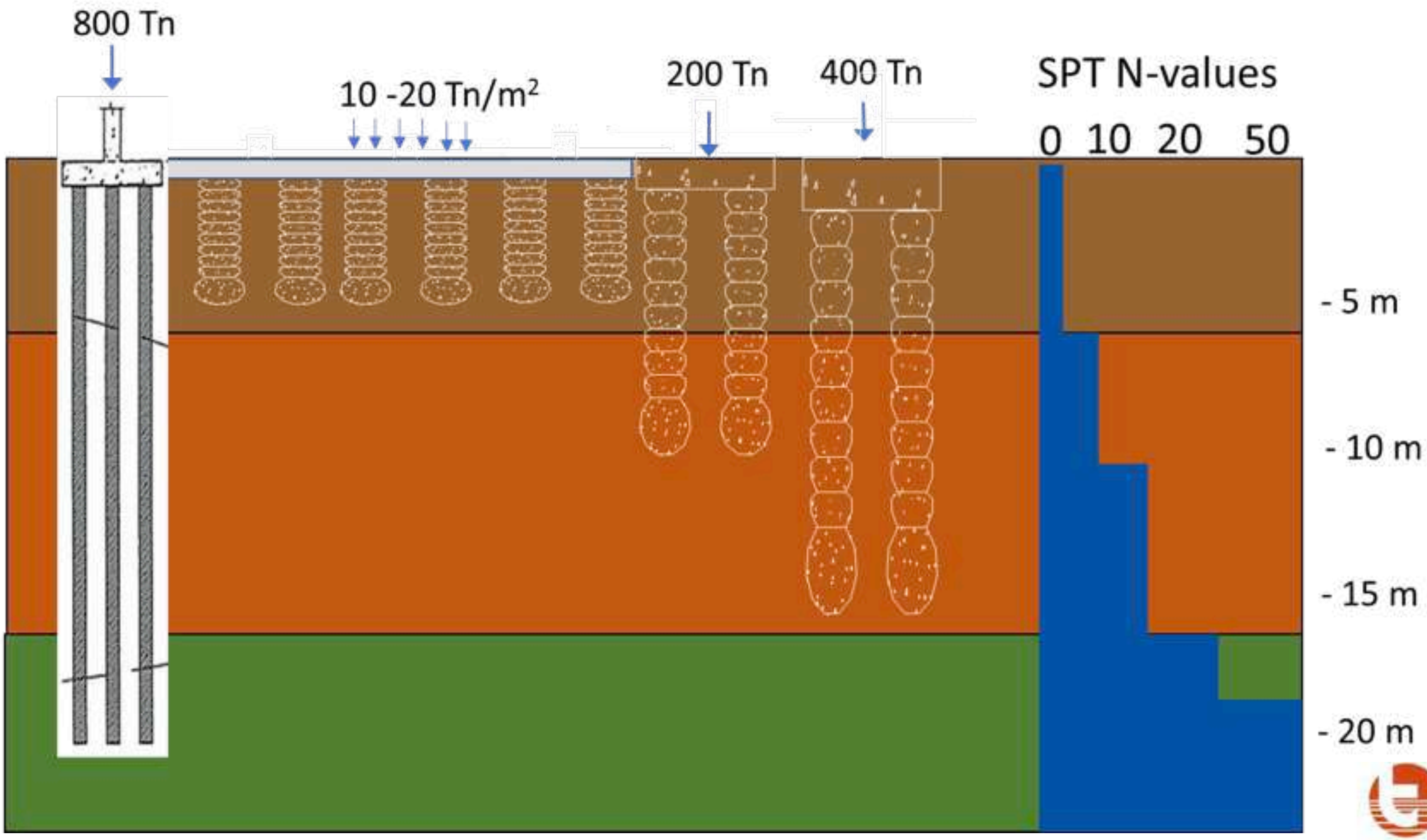
Comissão Portuguesa de Geossintéticos

Apoios

GEOPIER® Ground Improvement Options



Scoped of application – Intermediate Foundations



GRUPO TERRATEST

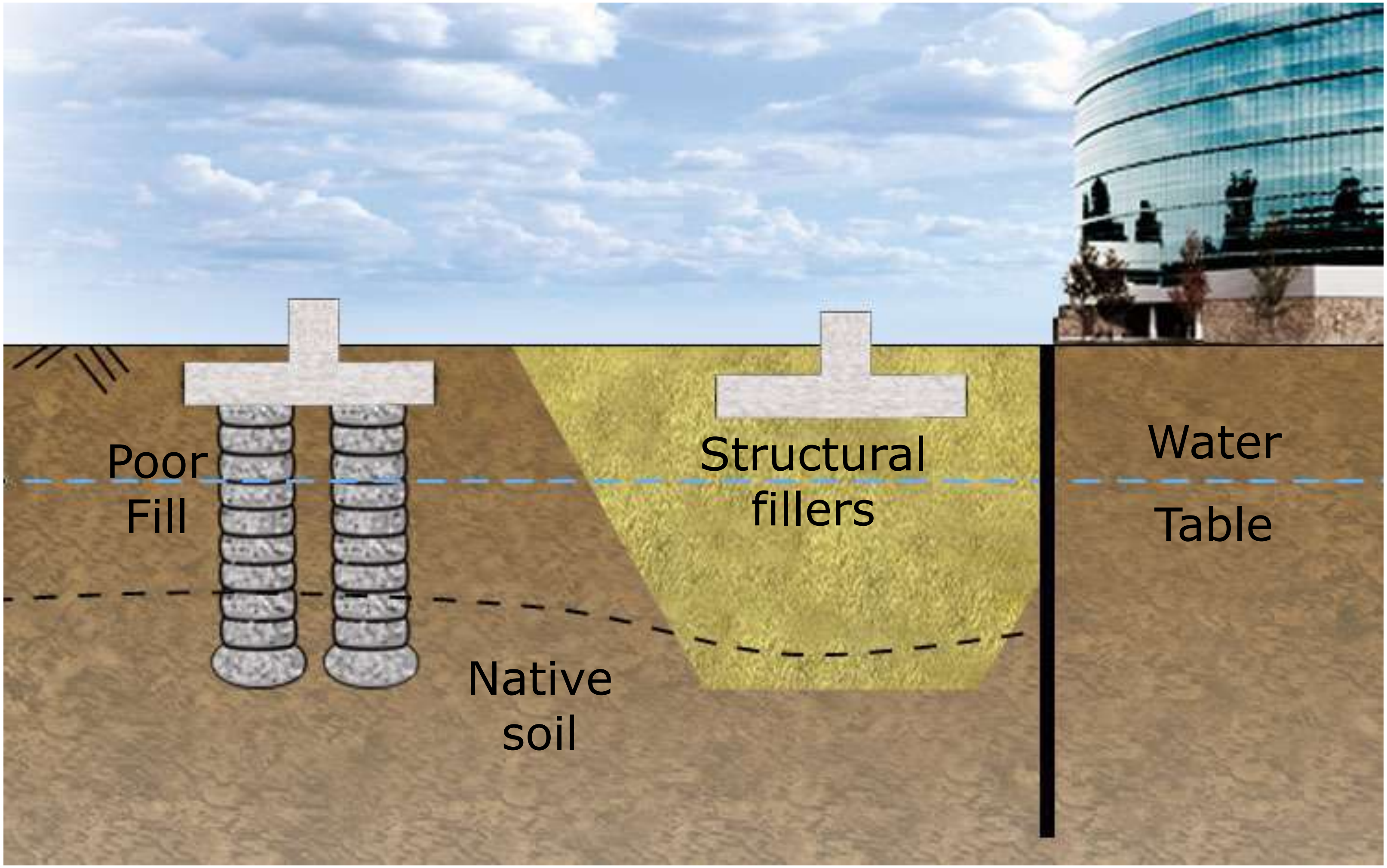
Preliminary Values for Geopier® Soil Reinforcement Design

SPT = N Blows Per Foot All Soils	UCS, kN/m^2 Fine-Grained Soils	Sands & Sandy Silts			Silts & Clays			Peat		
		Allowable Composite Footing Bearing Pressure, kN/m^2 (q_{all})	Geopier® Element & Footing Segment Capacity, kN (1) (Q_{cell})	Geopier® Element Stiffness Modulus, MN/m^3 (2) (k_g)	Allowable Composite Footing Bearing Pressure, kN/m^2 (q_{all})	Geopier® Element & Footing Segment Capacity, kN (1) (Q_{cell})	Geopier® Element Stiffness Modulus, MN/m^3 (2) (k_g)	Allowable Composite Footing Bearing Pressure, kN/m^2 (q_{all})	Geopier® Element & Footing Segment Capacity, kN (1) (Q_{cell})	Geopier® Element Stiffness Modulus, MN/m^3 (2) (k_g)
1-3	10 - 48	239	289	44.8	215	222	33.9	168	133	20.4
4-6	48 - 110	287	400	61.1	240	311	47.5	191	200	29.9
7-9	110 - 168	335	467	70.6	287	378	57.0	239	245	33.9
10-12	168 - 220	383	512	77.4	335	445	67.9	N/A	N/A	N/A
13-16	220 - 287	407	556	84.1	335	467	70.6	N/A	N/A	N/A
17-15	287 - 383	431	578	88.2	359	489	74.7	N/A	N/A	N/A
Over 25	Over 383	479	645	97.7	407	534	81.5	N/A	N/A	N/A

Notes:
1. For 0.46 m Geopier® elements, multiply by 0.45
   For 0.61 m Geopier® elements, multiply by 0.7
   For 0.91 Geopier® elements, multiply by 1.3
2. Geopier® element modulus to be confirmed by full-scale modulus test as determined by Geopier designer.

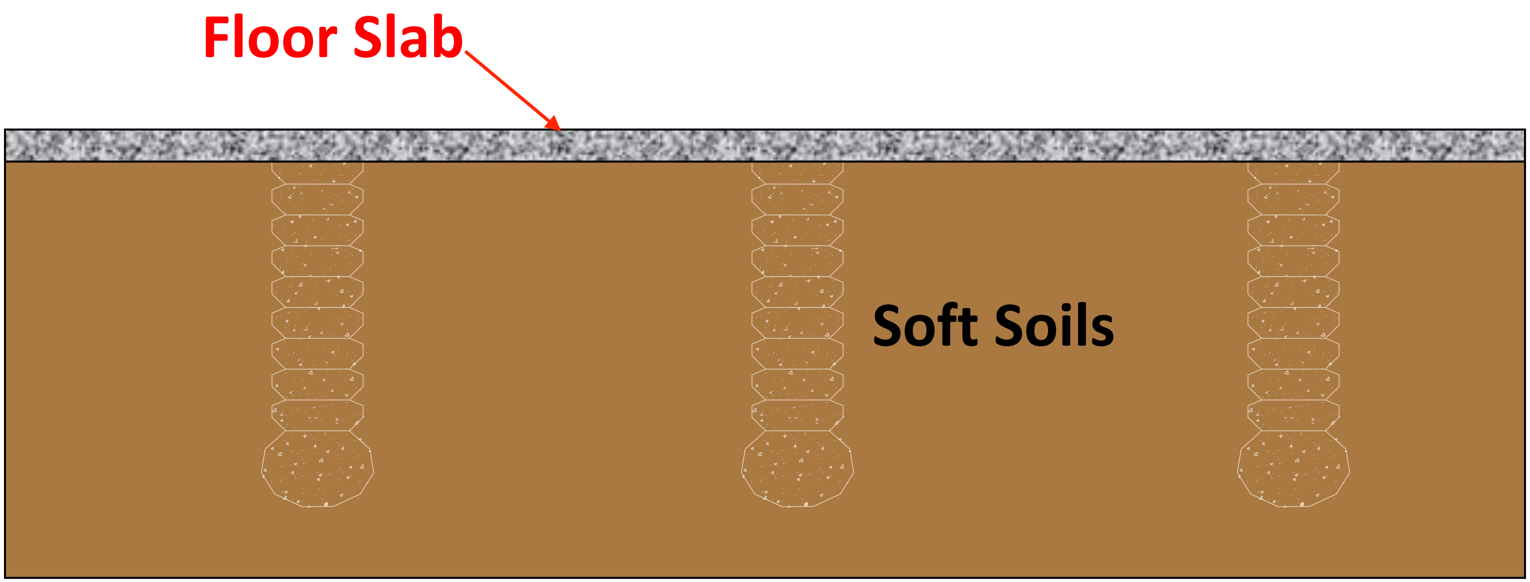
Common Applications

Replacement of drilled shafts and structural fillers



Common Applications

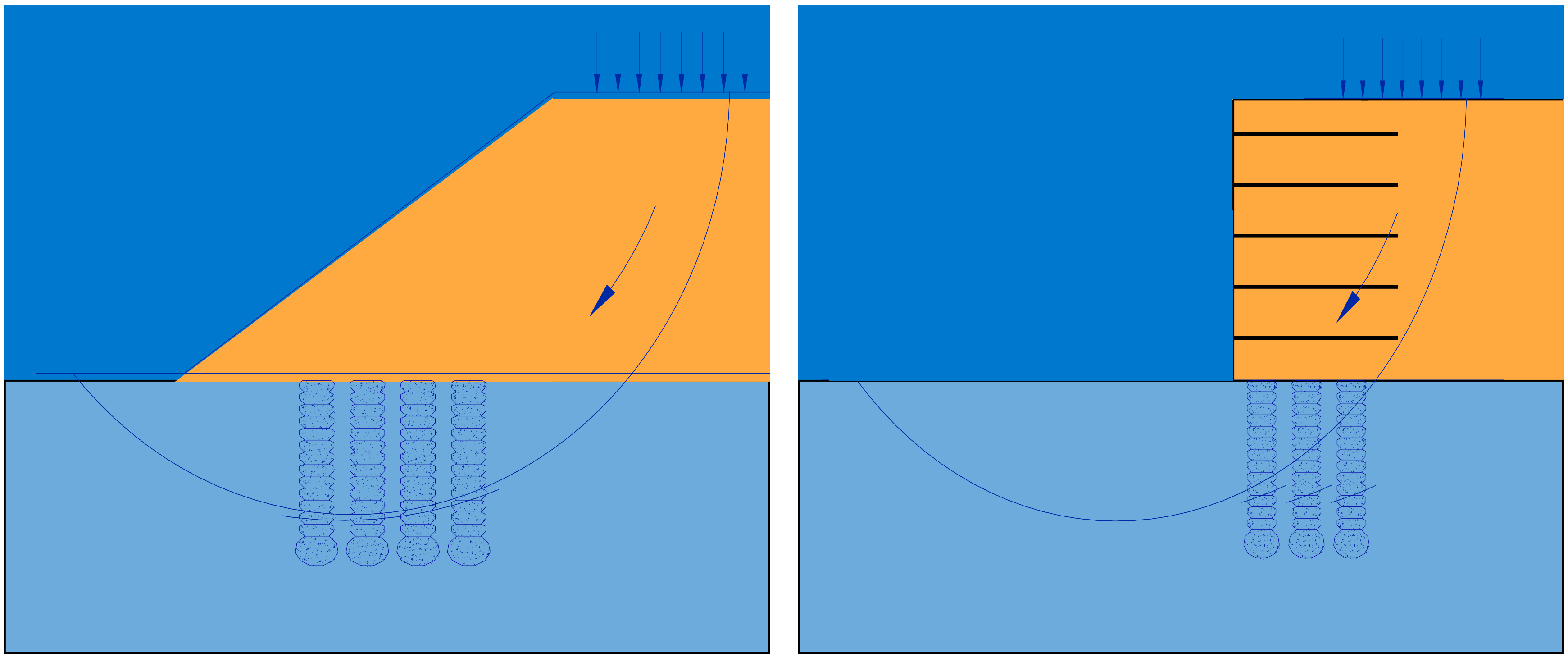
Replacement of structurally-supported floor slabs



Elements reinforce soft and compressible soils for support of relatively thin floor slabs.

Common Applications

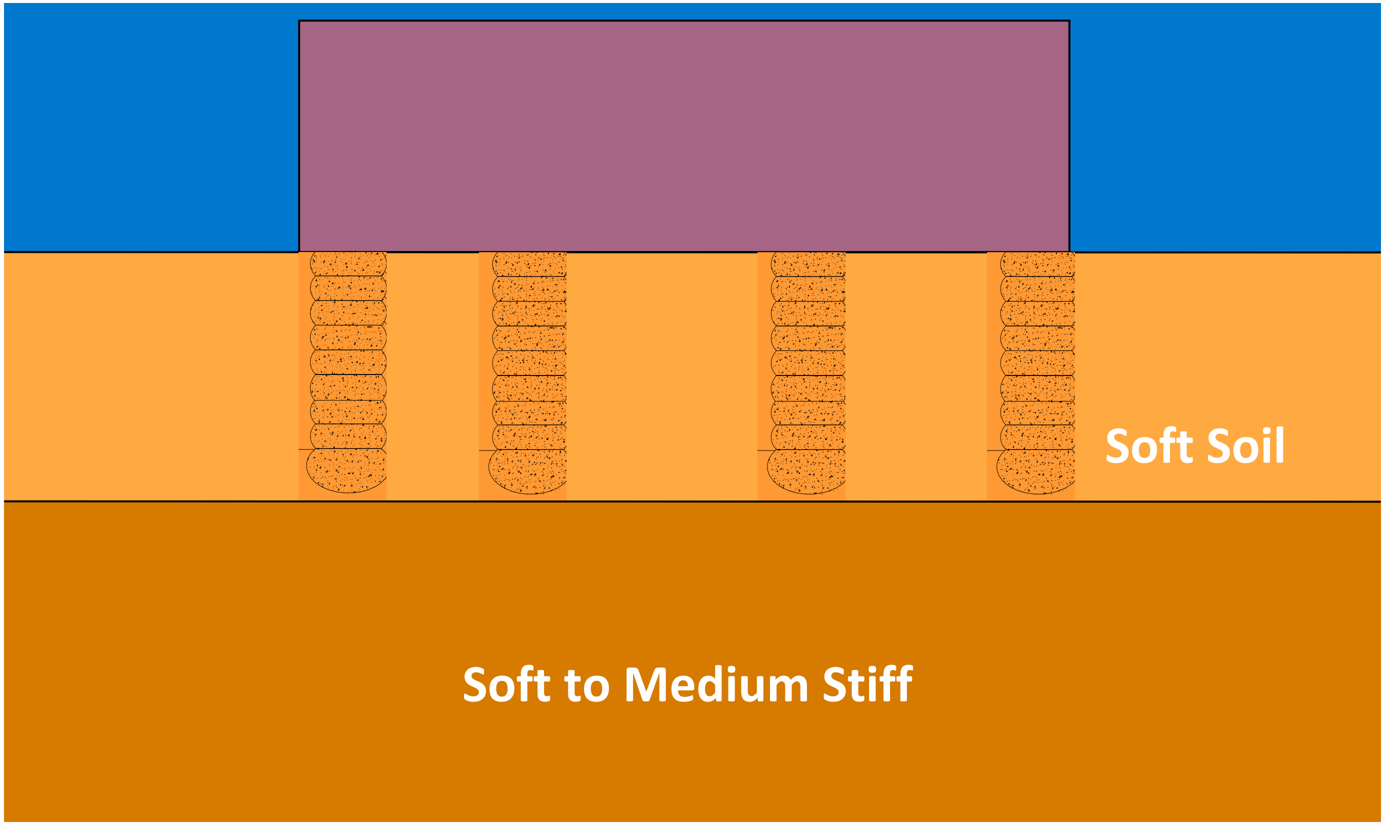
Provide global stabilization for embankments and retaining walls



Shear reinforcement in *Geopier improvement* zone

Common Applications

Provide support for tank and wind power tower foundations



Settlements control and increased rotational stiffness

GEOPIER® Solutions

"Drilling and compacting"

GP3™

X1®

"Displacement and Substitution"

IMPACT®

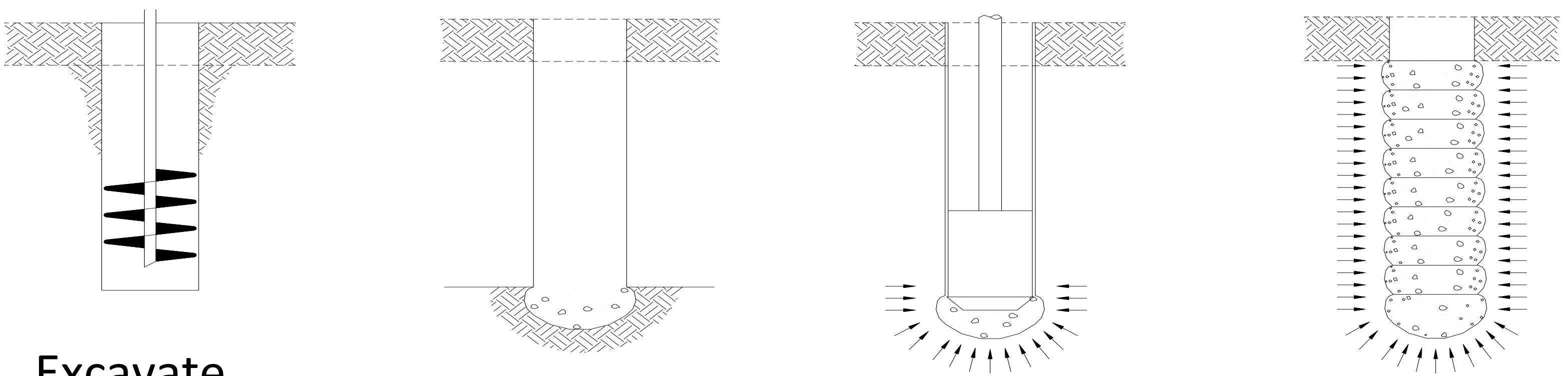
"Rigid Inclusions"

GEOCONCRETE®

GROUTED IMPACT®

GRUPO TERRATEST

Geopier System (GP3®) Construction



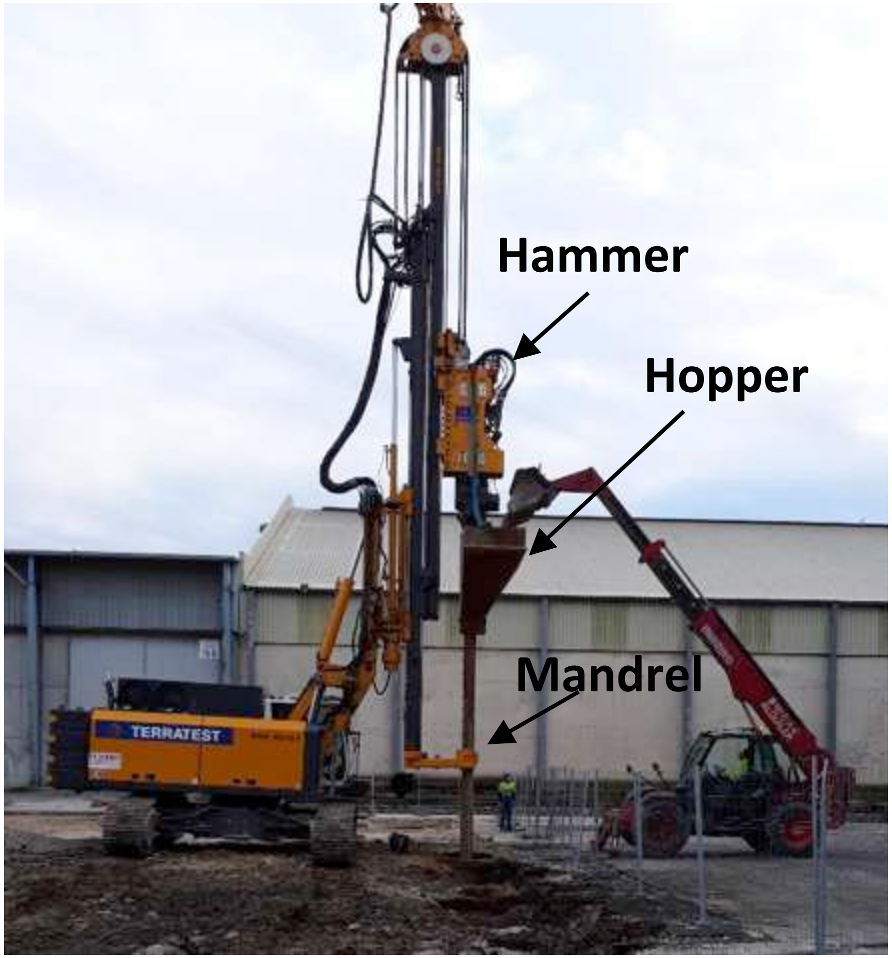
Excavate cavity

Open-graded stone

Tamp bottom bulb

Well-graded stone tamped in 30 cm lifts

Impact® Geopier Construction



Pre-stressing and pre-deforming the surrounding soils. (Over-consolidation)

Displacement Method - good for saturated sands and caving soils

IMPACT®

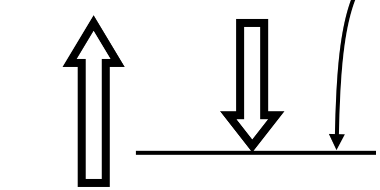
GRUPO TERRATEST

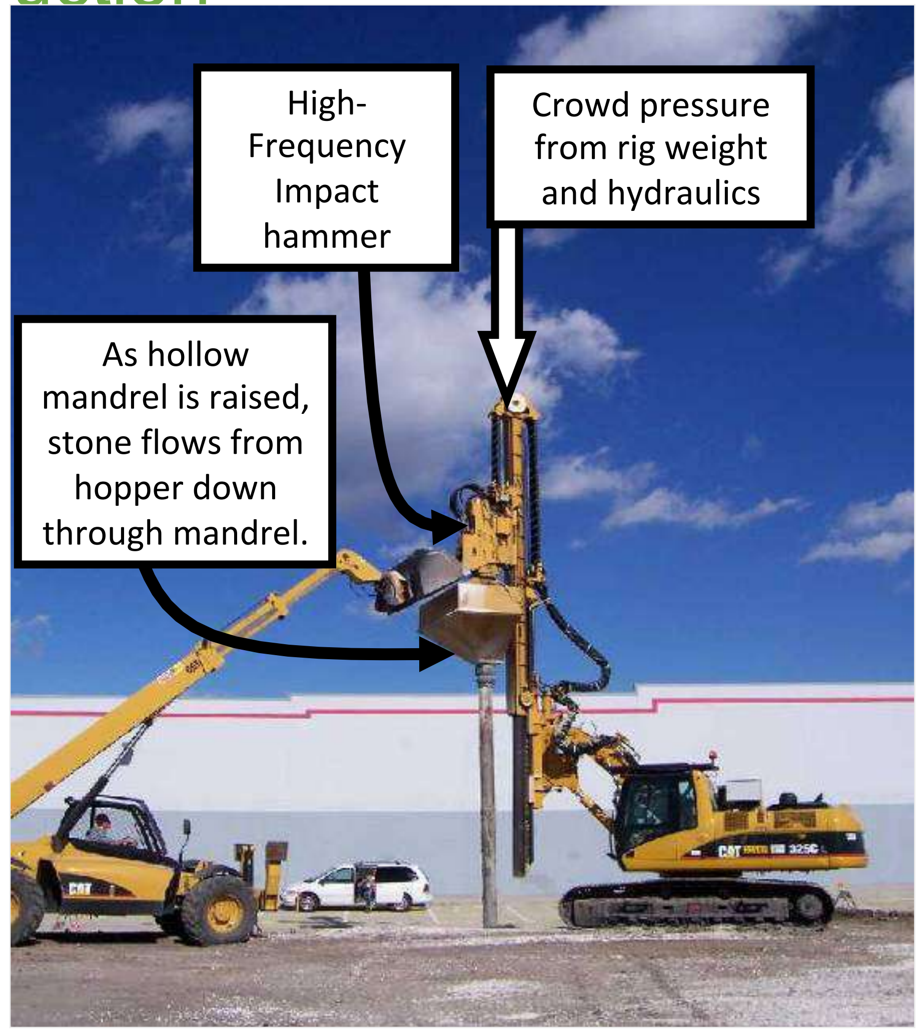
Impact® Geopier Construction

After driven to full depth, mandrel is raised up 1 m

Then driven back down 70 cm

Dense, 30 cm lifts





IMPACT®

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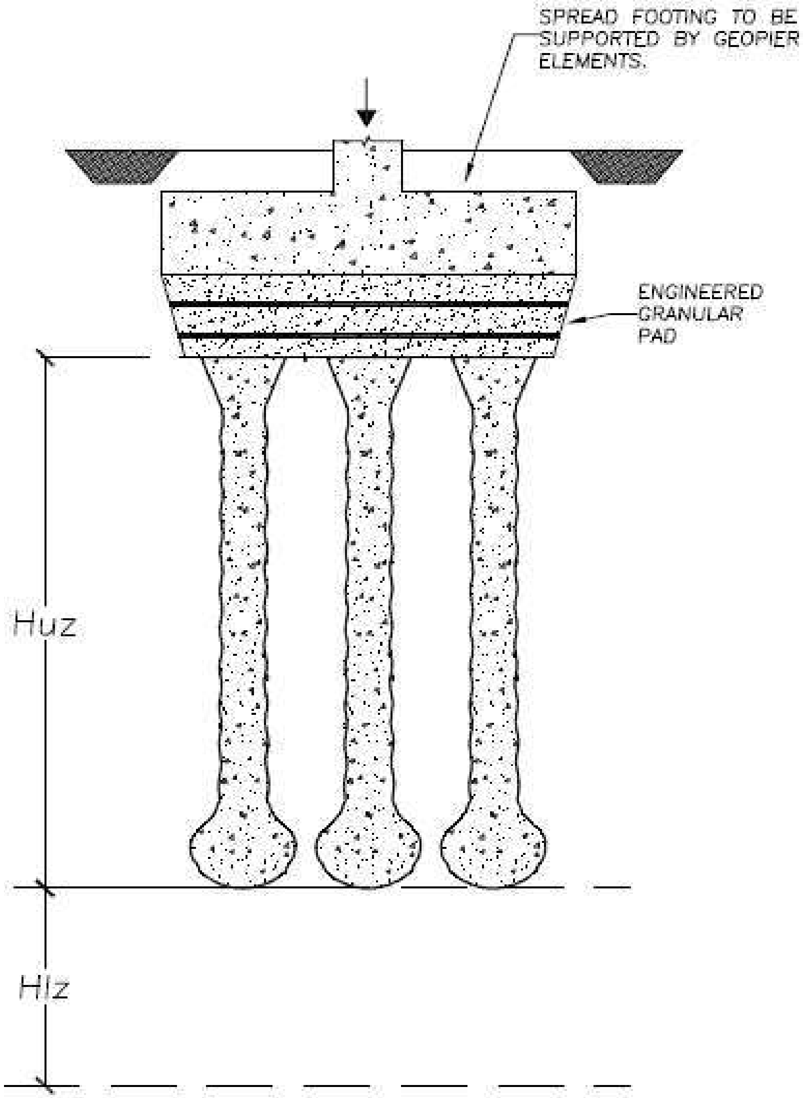
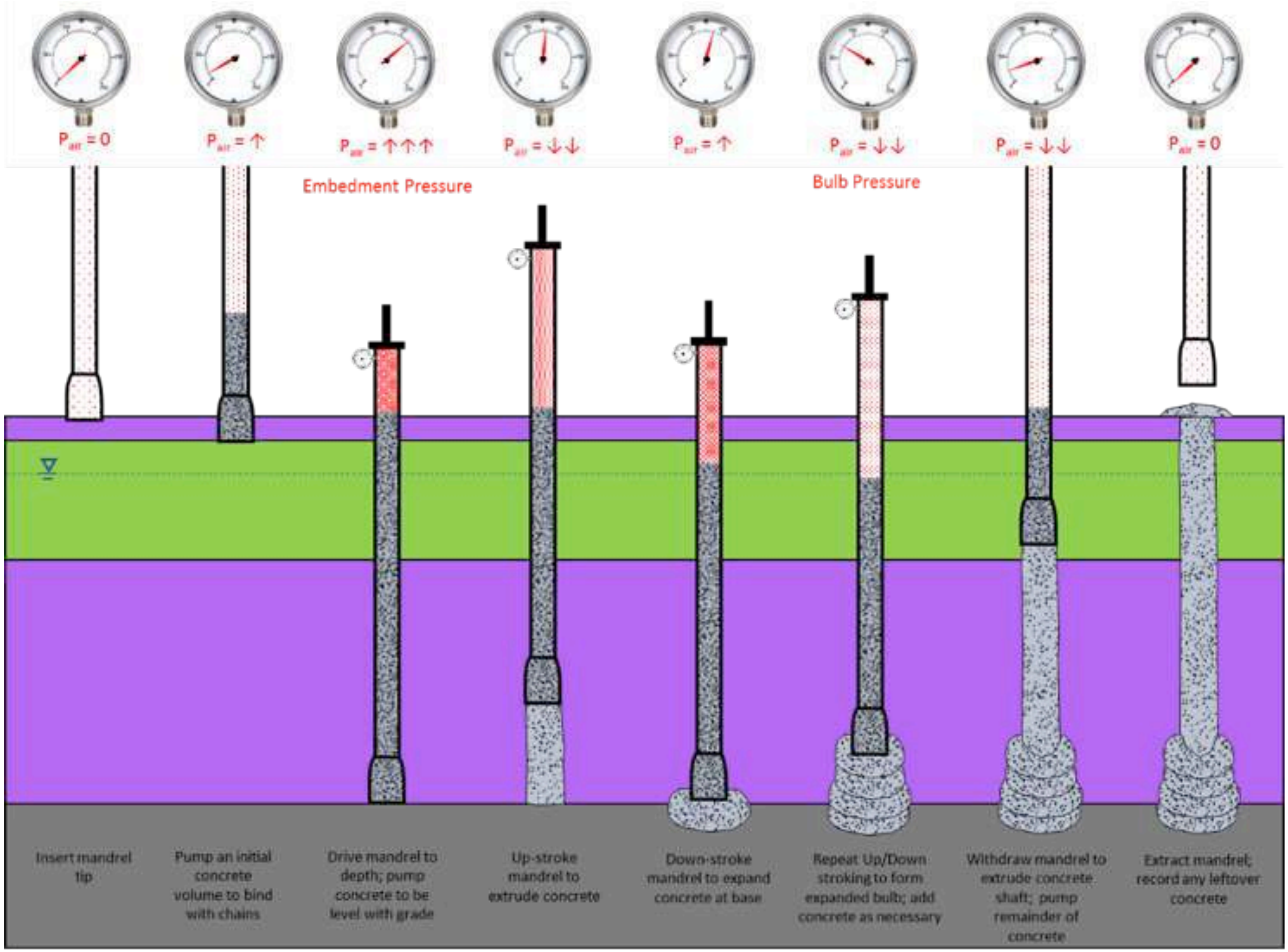
Geopier Rigid Inclusions – Geo Concrete Column (GCC®)



GEOCONCRETE®

GRUPO TERRATEST

Geo Concrete Column (GCC®) Construction



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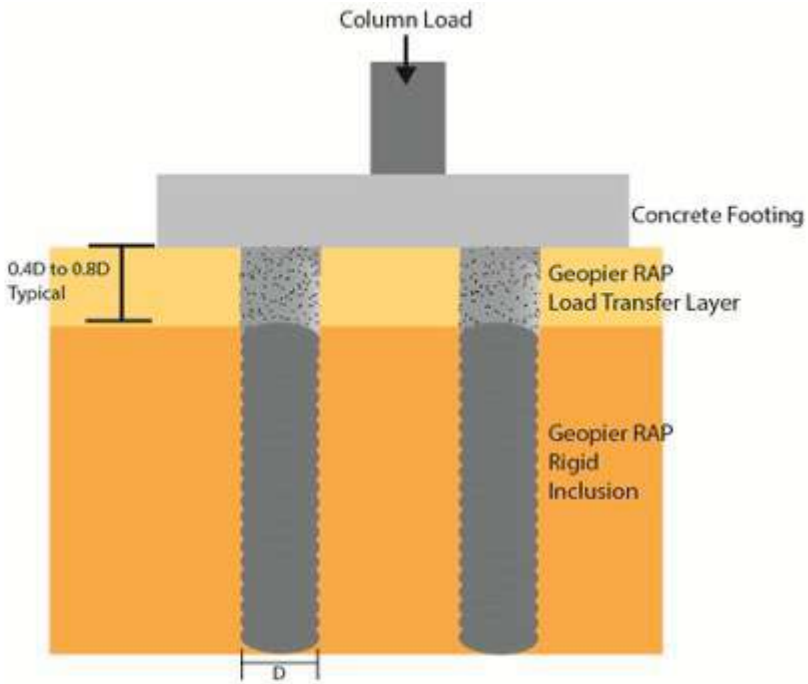
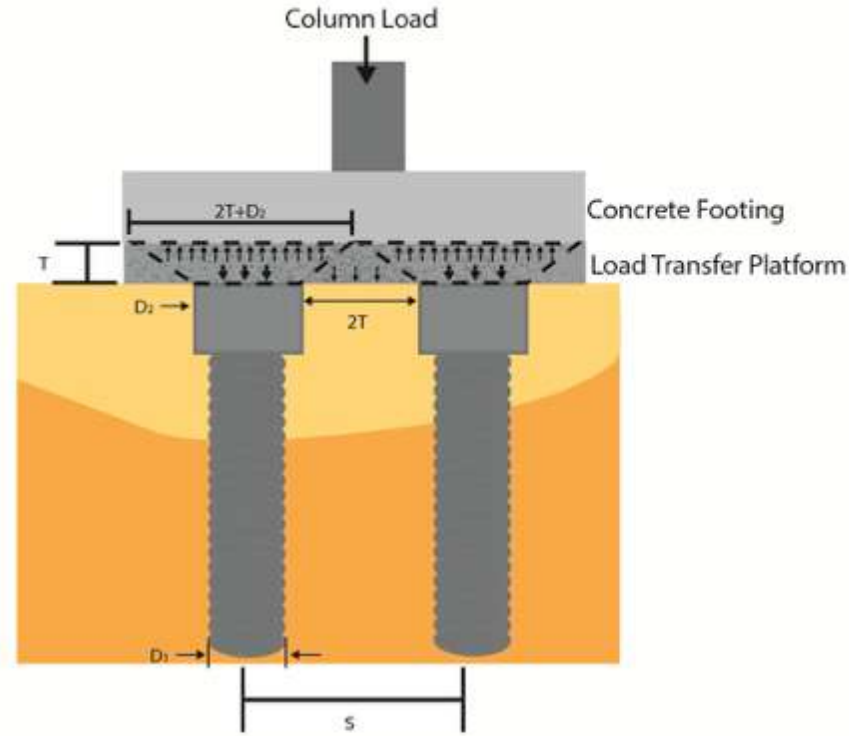
Geo Concrete Column (GCC®) Design





- **Design for both Structural and Geotechnical Performance**
  - Structural is Function of unconfined Compressive Strength
  - Geotechnical is a function of skin friction and end bearing
- **Use of an Expanded Head to reduce LTP.**
- **LPT and GCC are interdependent.**

Thank you for your attention

GRUPO TERRATEST

Compaction grouting

A technology of soil improvement (almost) unknown in Portugal

José Luiz Antunes
Keller Grundbau GmbH – Portugal Branch

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Compaction grouting

Content

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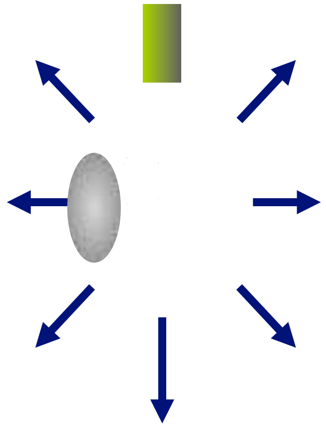
Compaction grouting

Concept

Displacement injection



- Compaction grouting technology is based on the soil injection of a **high consistency mortar**, so that the injected mixture **does not penetrate the ground**, being **concentrated around the injection point**

- The injected material fills the voids and **causes the lateral displacement of the soil**, densifying it and stabilizing it in the treated zone. The hardening of the mortar provides an **increase of resistance in the injected zone**

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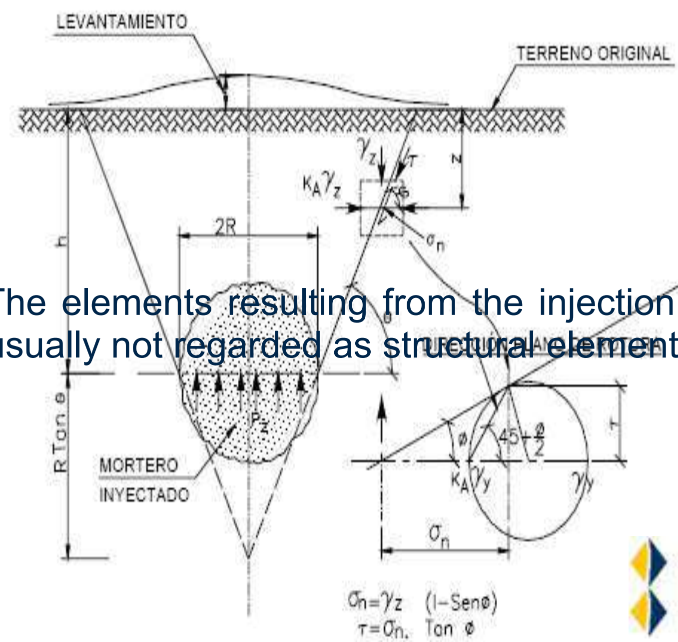
Compaction grouting

Concept

"column" made visible

- The vertical tension of the treated layer must ensure that the thick mortar moves the ground horizontally avoiding to cause surface heaves

- re
ut



- The elements resulting from the injection are usually not regarded as structural elements

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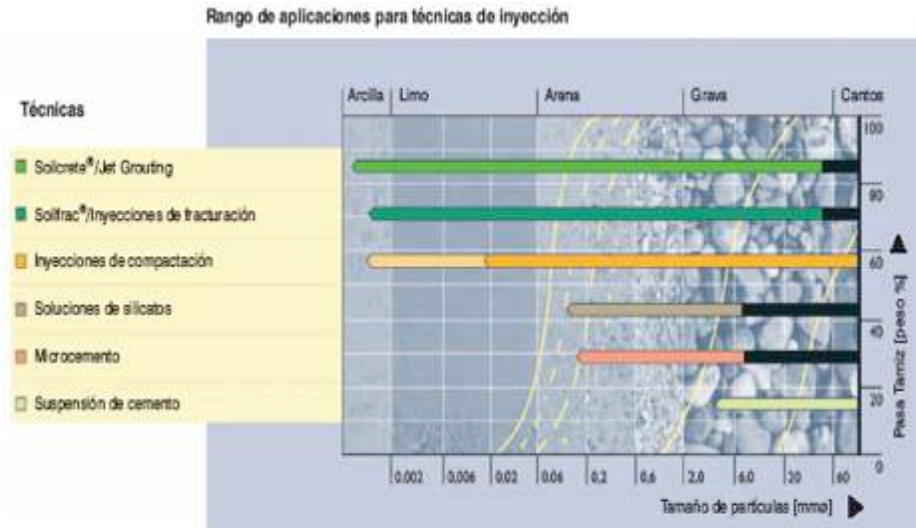
Compaction grouting

Application field

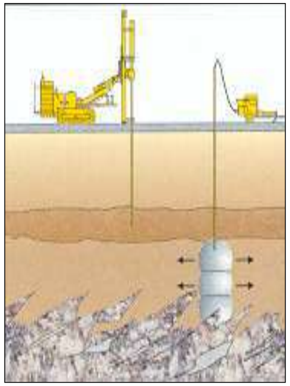


- In general, in soils with 4 <SPT <20
- Granular soils
- Dry cohesive soils or with low W%

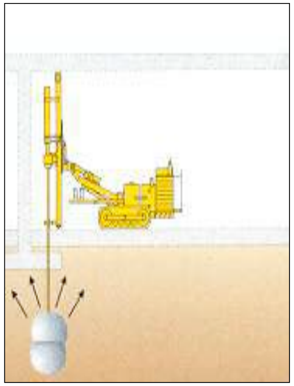
Compaction grouting

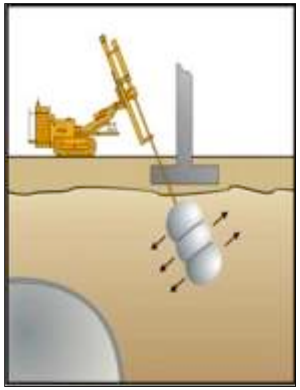
Application field

- **Soil improvement**

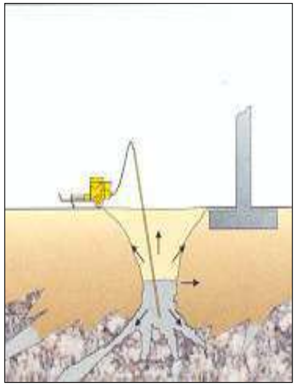


- **Structural underpinning**

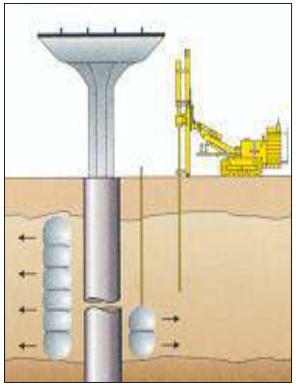




- **Cavities filling**



- **Increase of bearing capacity**



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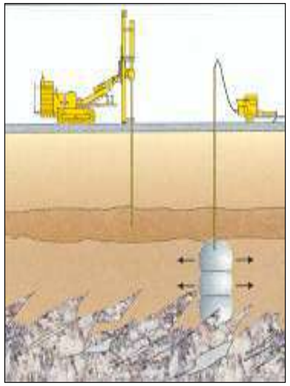
Compaction grouting

Application field

- **Soil improvement**



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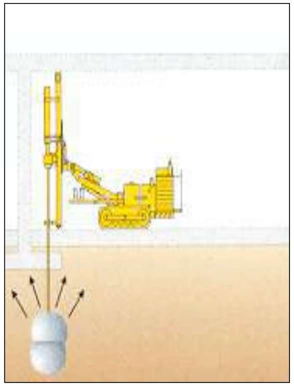

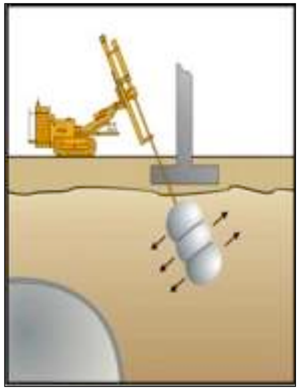

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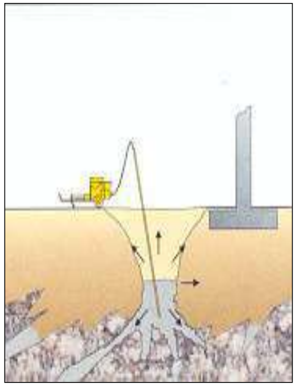

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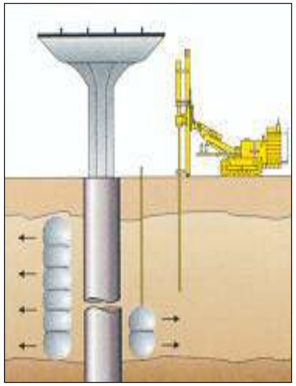

LIQUEFACTION!

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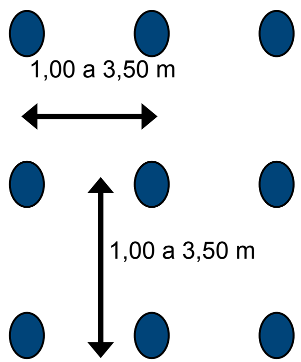
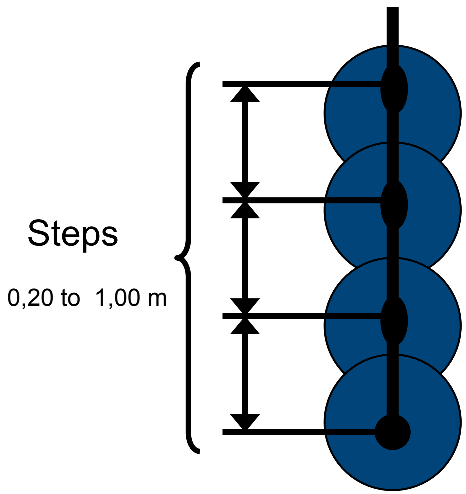
Compaction grouting

PLAN VIEW



CORTE



Design parameters

- Injection volume ratio

$$\frac{\text{Injected volume}}{\text{Volume of treated soil}} = 5 - 15\%$$

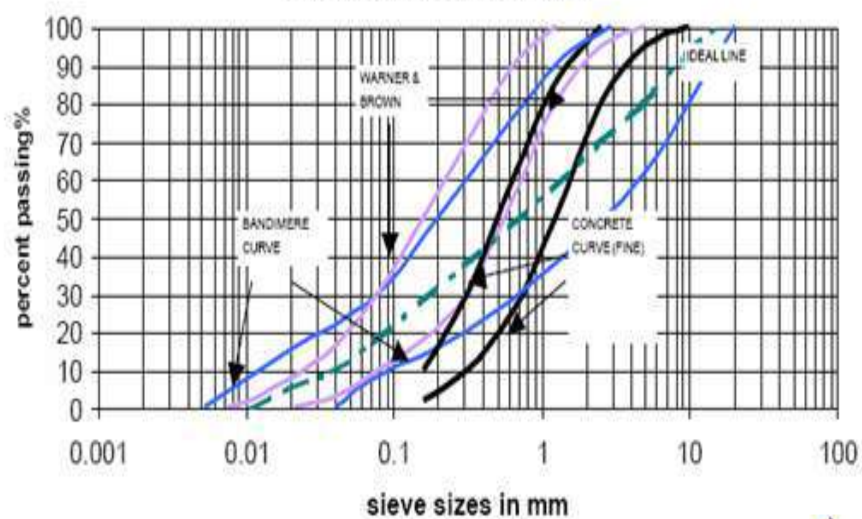
- Injection during drilling advance or tool withdrawal
- Sequence of the drillings/injections in order to obtain the maximum possible soil confinement
- Drillings grid: 1.0 to 3.5 m
- Steps or stages of injection: 0,20 – 1,00 m

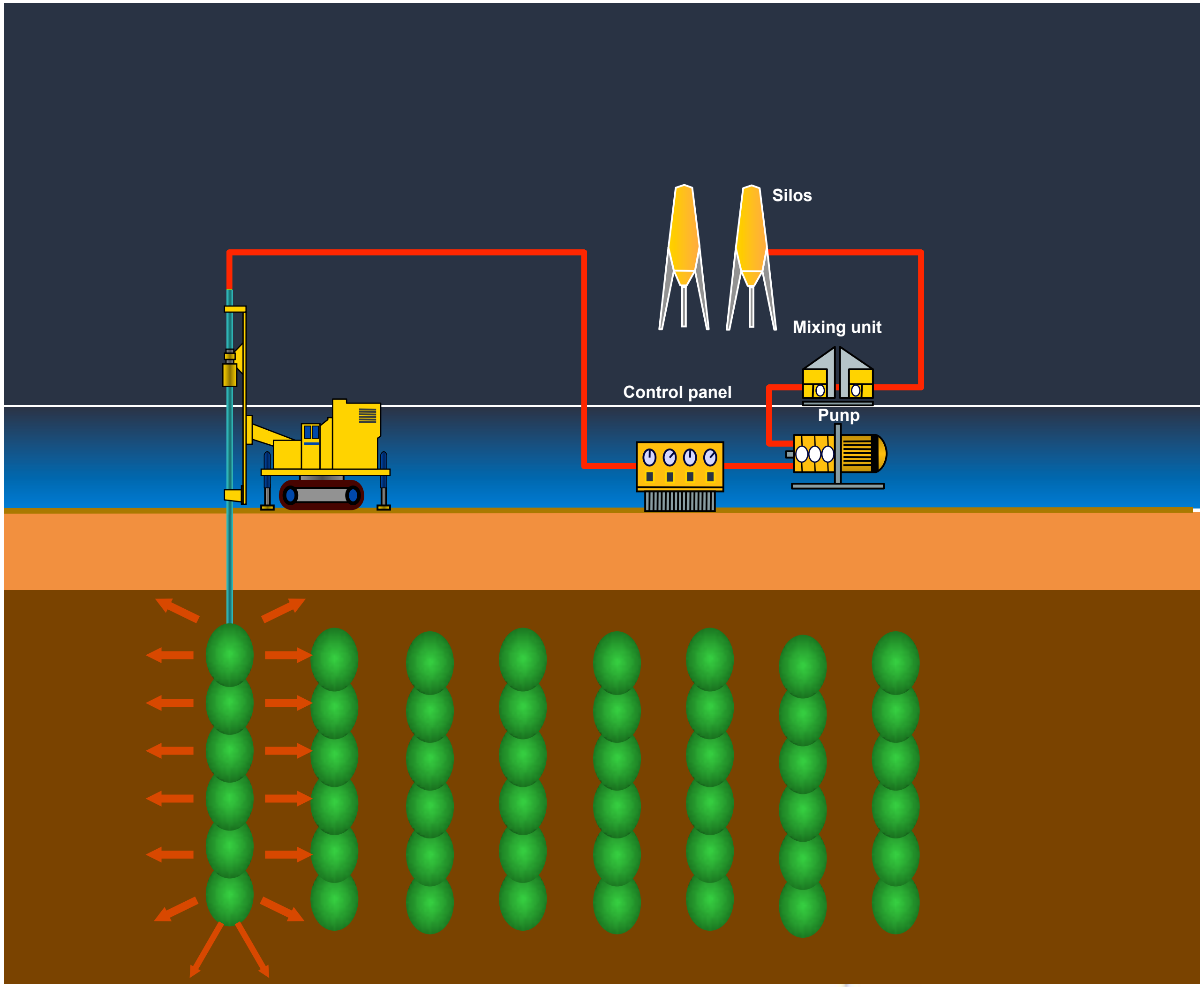
Compaction grouting

Design parameters

- Injection pressure: between 5 and 30 bar
- High consistency mortar: Cone Abrams between 3 and 8 cm

Figure 1 Suggested Particle Size Distribution For Compaction Grout Mixes





Compaction grouting – Execution

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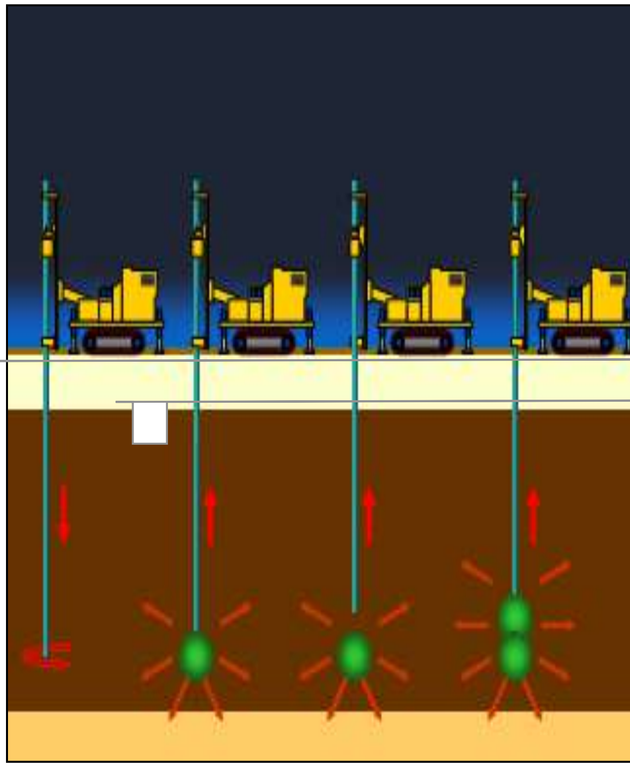
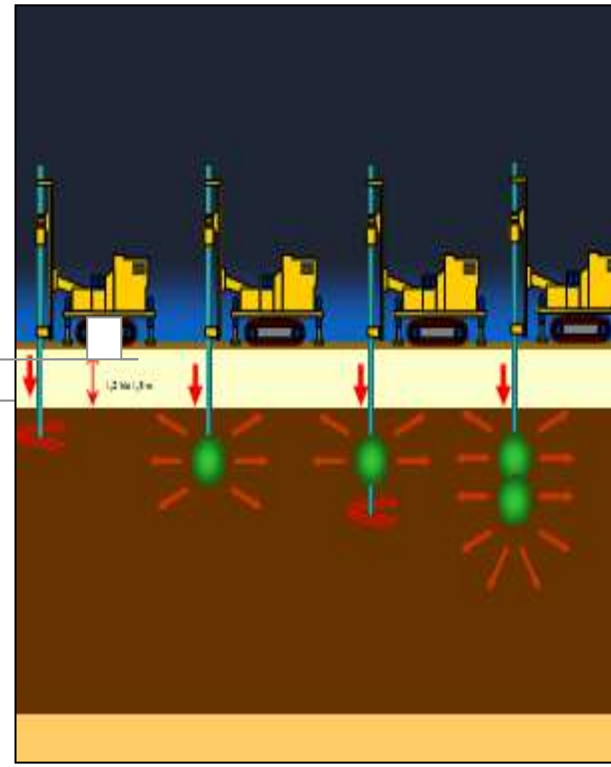
Compaction grouting

Execution

UPWARDS (*Bottom-up*)



DOWNWARDS (*Top-down*)



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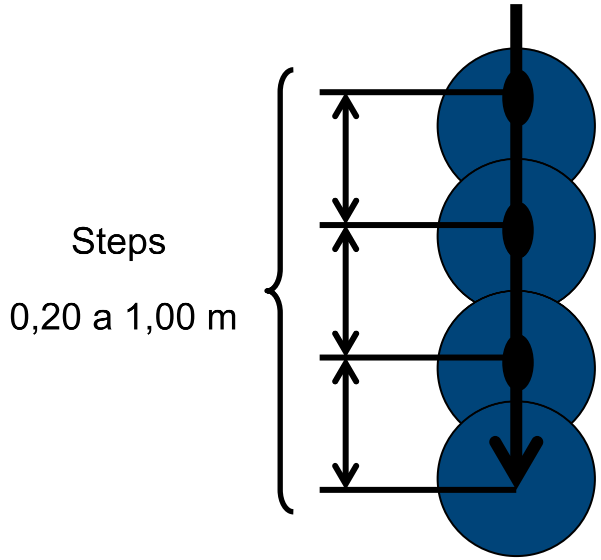
Compaction grouting

Execution



Ending criteria for each step

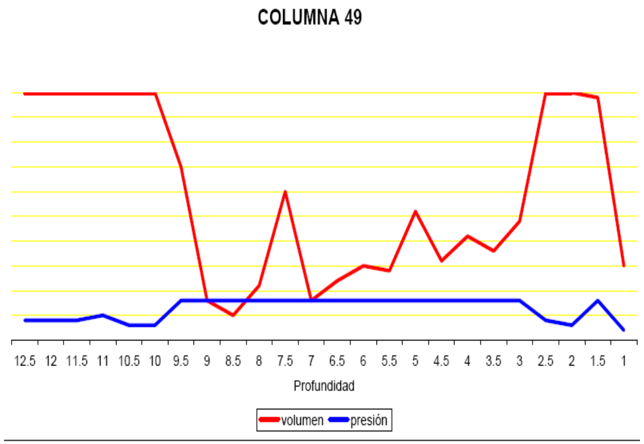
- By volume
- By pressure
- By surface displacement
- By mortar reflux at the mouth of the hole

Compaction grouting

Monitoring

- Systematic control of mortar by testing it with the Abrams Cone (Slump test)

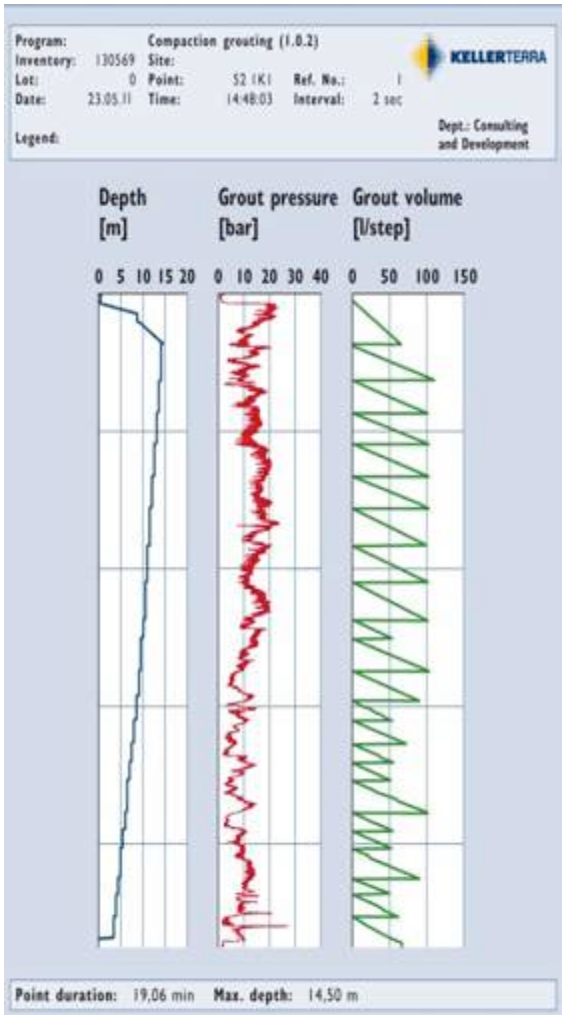
- Control of execution parameters

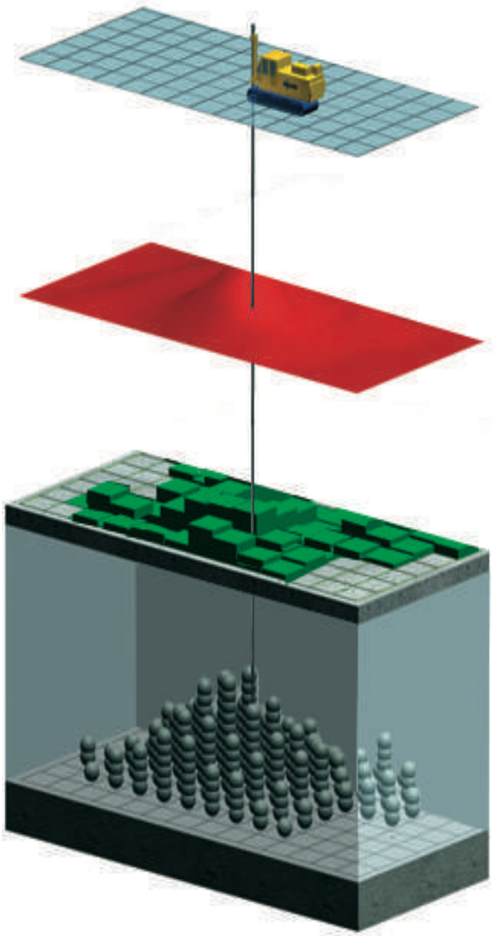


- Control of movements (heaves) at the working platform or structure/foundation

Compaction grouting

Parameter monitoring





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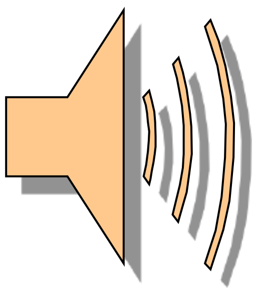
Compaction grouting

Displacement monitoring at the surface

Rotary laser and rulers



Precision optical surveying

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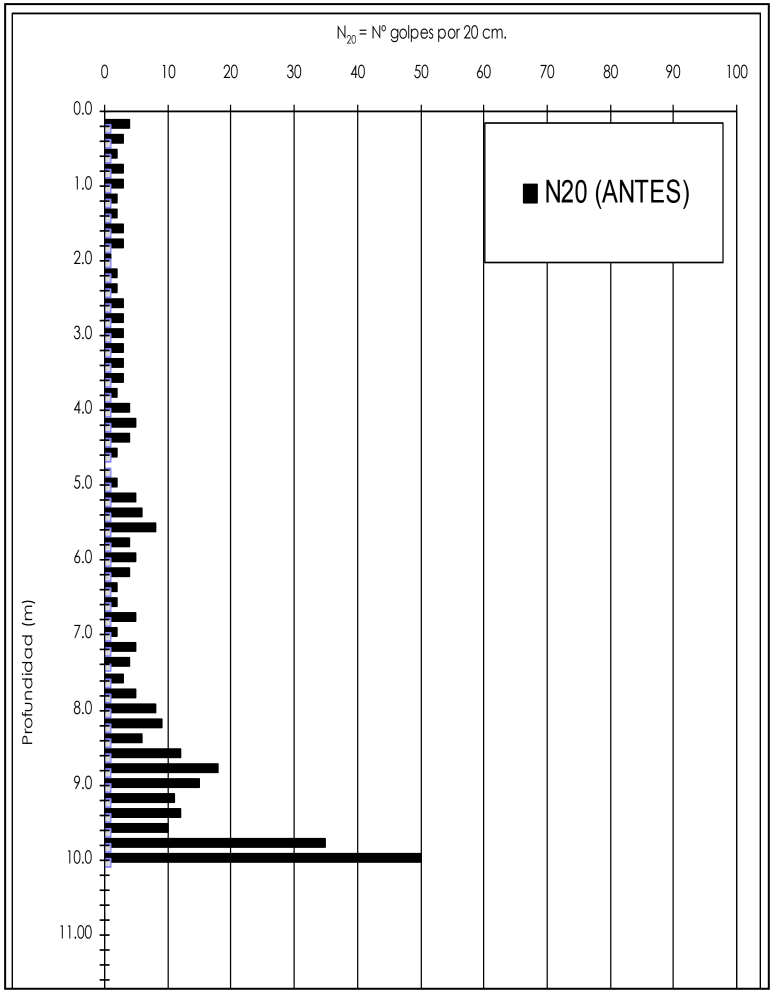
Compaction grouting

Monitoring improvement results



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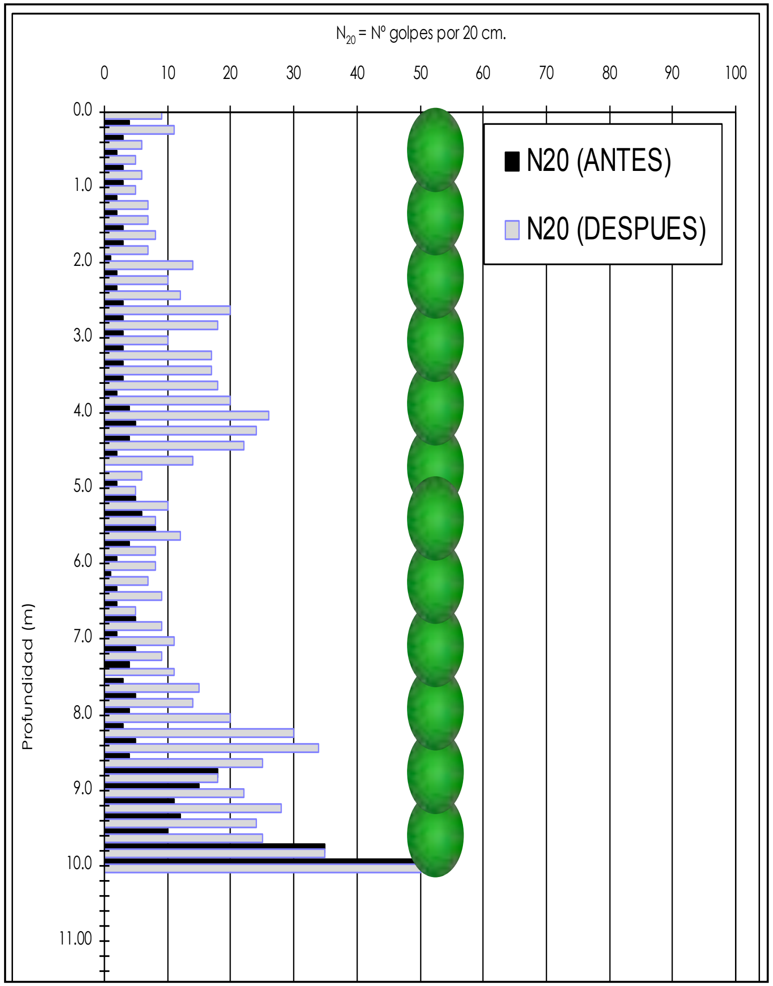
Compaction grouting

Monitoring improvement results



- Aumento de N_{20} entre 2 e 6 vezes

- Aumento de D_R entre 1,5 e 3 vezes

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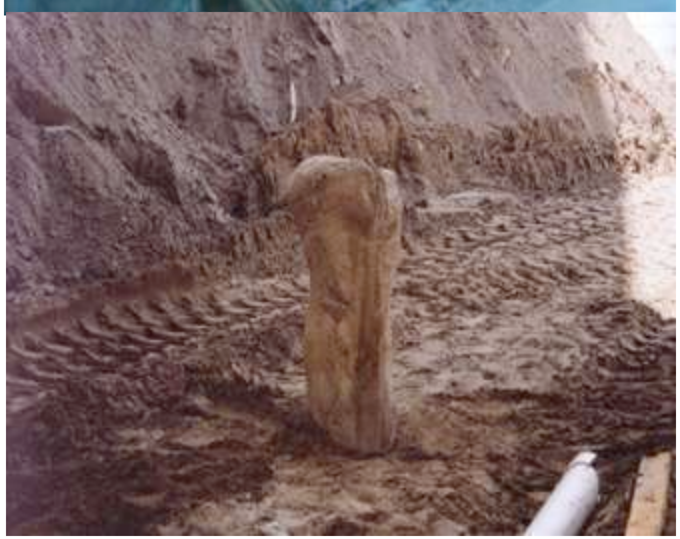
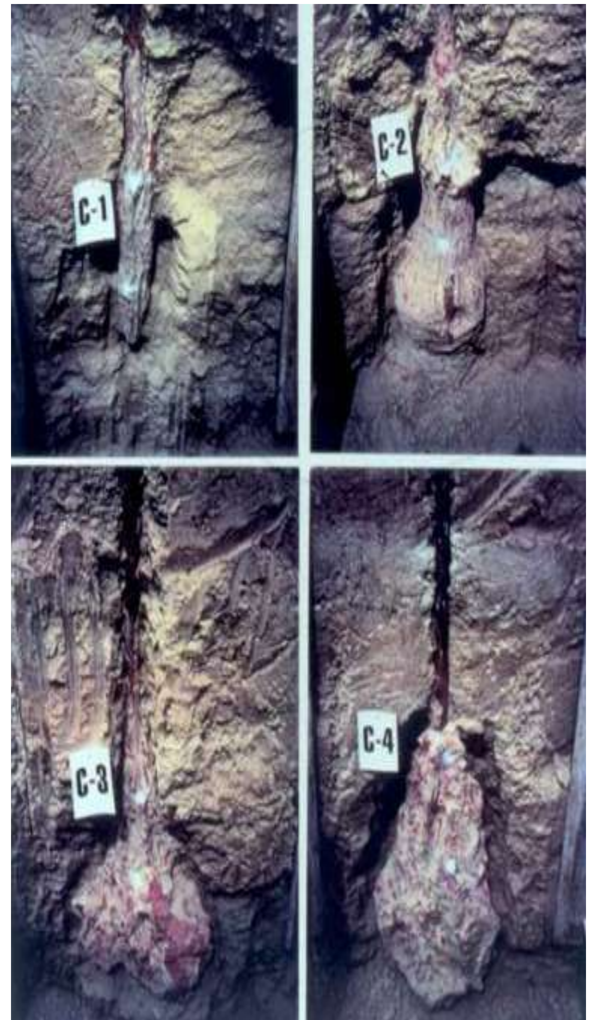
Monitoring by excavation control





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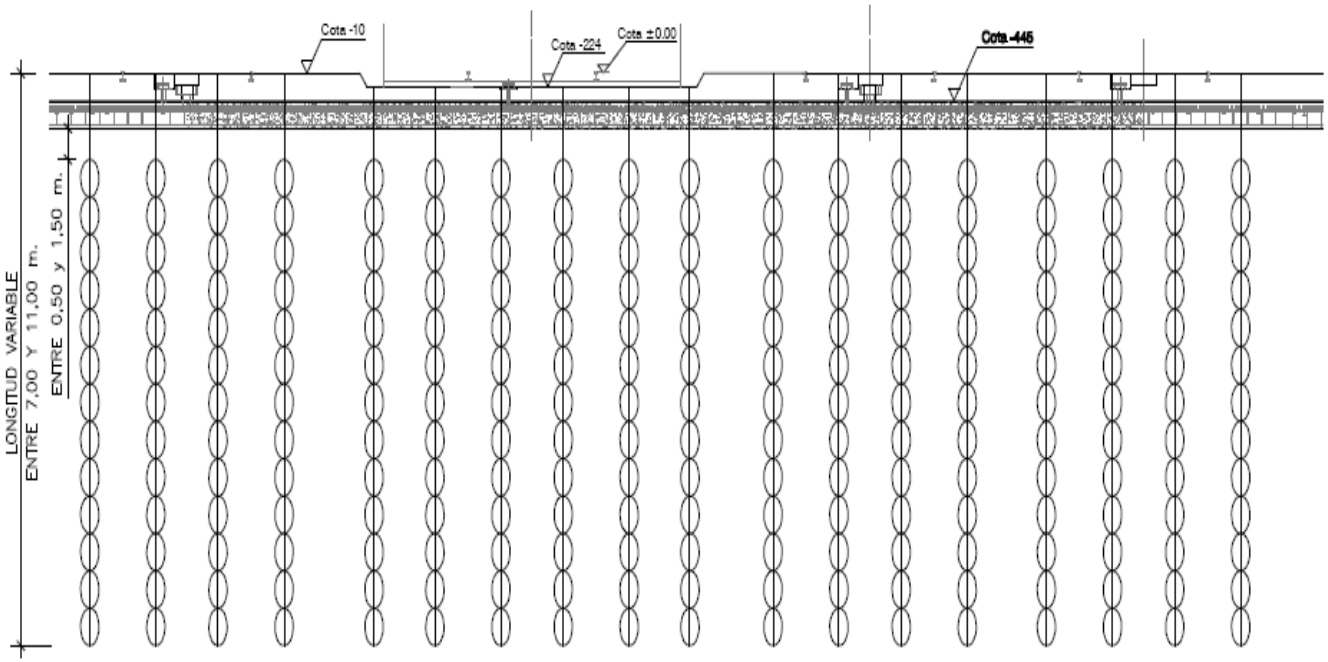
Example 1

Change of the original load plan in an industrial unit



Compaction grouting

Exemplo 1

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Compaction grouting

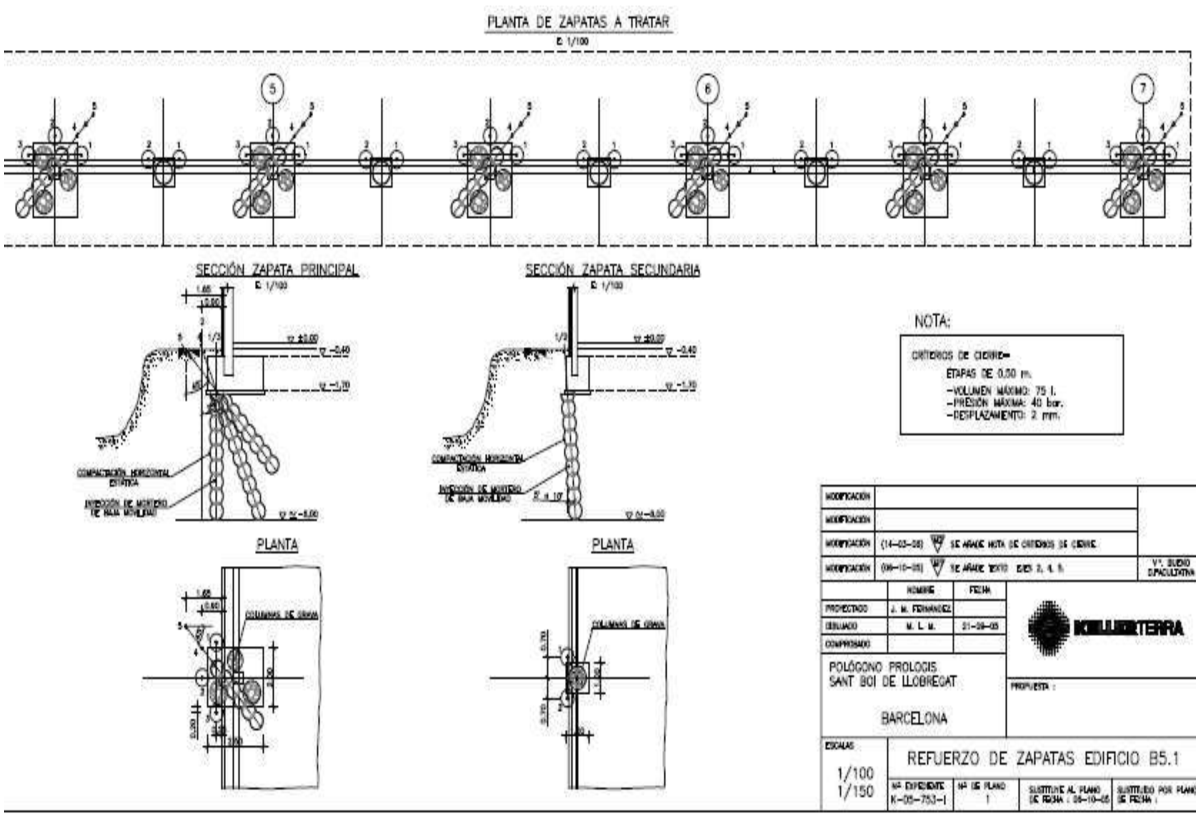
Exemplo 1

Compaction grouting

Example 2

:

Change in the surrounding conditions of an industrial warehouse due to loss of fines by water percolation



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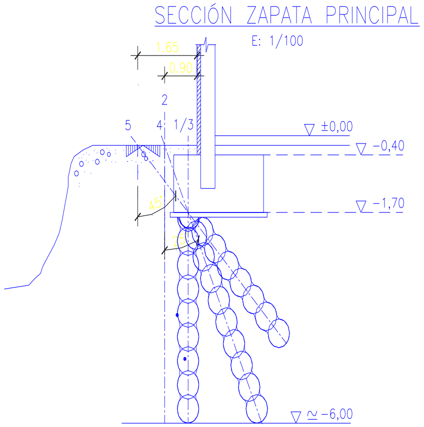
Example 2



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Example 3

Rehabilitation of a road bridge after flood damage

Compaction grouting

Conclusions

- Wide range of treatable soils
- Treatment of soil in localized areas
- Quick installation and execution from the inside and/or outside of structures
- Possibility to work in limited spaces (headroom <3,0 m)
- Suitable to apply in hard to reach places
- Non-destructive process adaptable to the existing foundations
- Clean process - does not generate spoil material
- Does not require structural connection to the existing foundation
- Economic alternative when compared with other suitable indirect foundations or soil replacement

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Obrigado!

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jose.antunes@Keller.com

Tratamentos de recalce de lajes com recurso a inclusões semi-rígidas por colunas de solo-cimento
Procedimento SPRINGSOL

José Luis Arcos

Director Técnico Rodio Kronsa

RODIO KRONSA
Una empresa de SOLETANCHE BACHY

Organização

Sociedade Portuguesa de Geotecnia

CPGT
Comissão Portuguesa de Geotecnia nos Transportes

igs Portugal
Comissão Portuguesa de Geossintéticos

vfx Ligações Fortes
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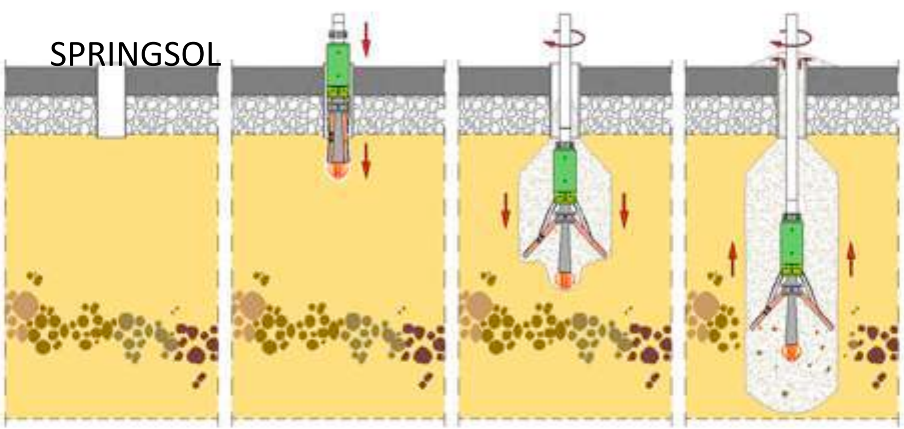
ORDEM DOS ENGENHEIROS

2º Seminário
Geotecnia nos Transportes
Desafios Associados ao Melhoramento de Solos em Zonas

Sociedade Portuguesa de Geotecnia
CPGT Comissão Portuguesa de Geotecnia nos Transportes
igs Portugal Comissão Portuguesa de Geossintéticos
Câmara Municipal de Vila Franca de Xira
www.cm-vfxira.pt

Tratamentos de recalce de lajes com recurso a inclusões semi-rígidas por colunas de solo-cimento.
Procedimento SPRINGSOL

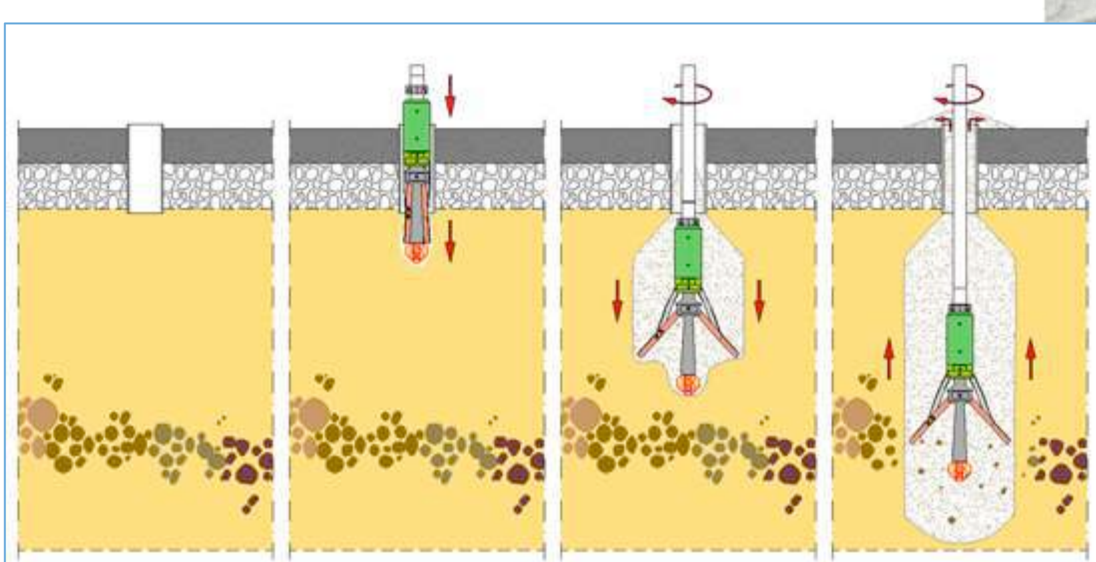
José Luis Arcos



Build on us

Tratamentos de recalce de lajes com recurso a inclusões semi-rígidas por colunas de solo-cimento. Procedimento SPRINGSOL

SPRINGSOL



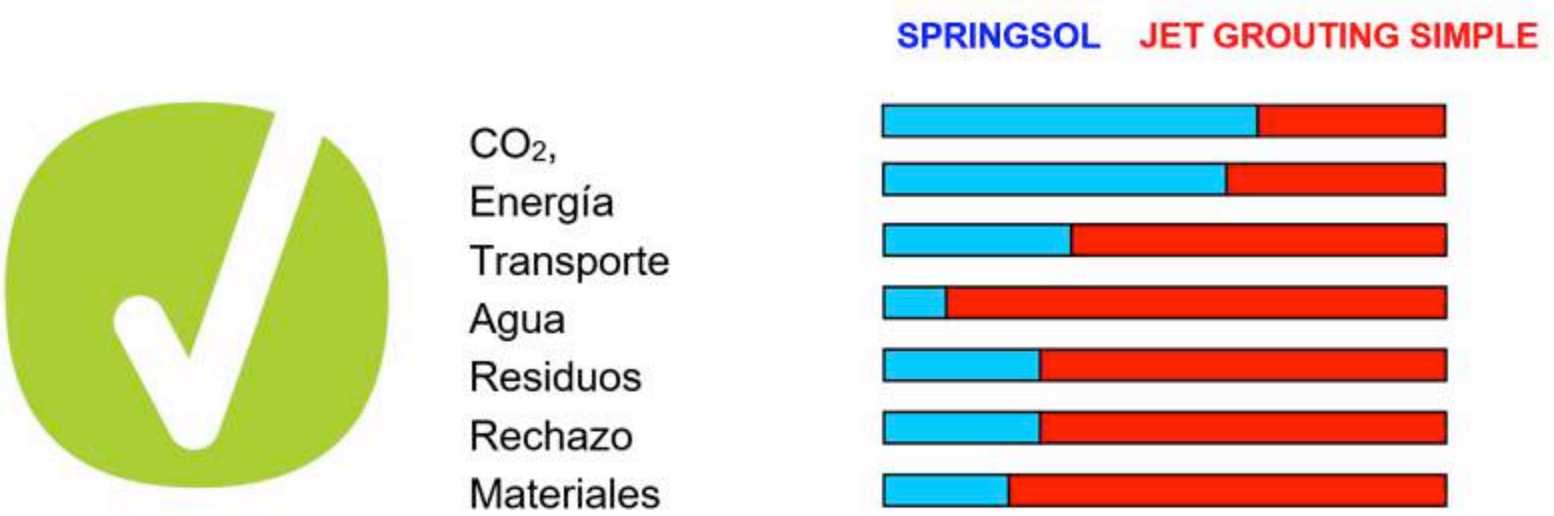
Tipos de tratamentos de terreno com recurso a injecções de ligantes

Tratamento do terreno por injecção, através da desintegração do solo e da execução da mistura de ligantes

SOIL-MIXING:

- Processo Básico:
  - O solo é desintegrado através de uma ferramenta mecânica
  - Incorpora-se um ligante hidráulico ao solo
  - Produz-se uma mistura de solo com ligante.
- Ligantes:
  - Cimento, Cal ou um outro ligante especialmente desenhado para uma determinada função
  - O ligante aplica-se em forma de pó ou líquido (pré-misturado com água), distinguindo-se assim o método seco do húmido;
- Resultado:
  - Obtém-se uma inclusão de solo-ligante em forma de coluna, em forma de elemento linear, de trincheira, parede ou painel rectangular,…

Comparação entre colunas de Springsoil e colunas de jet-grouting



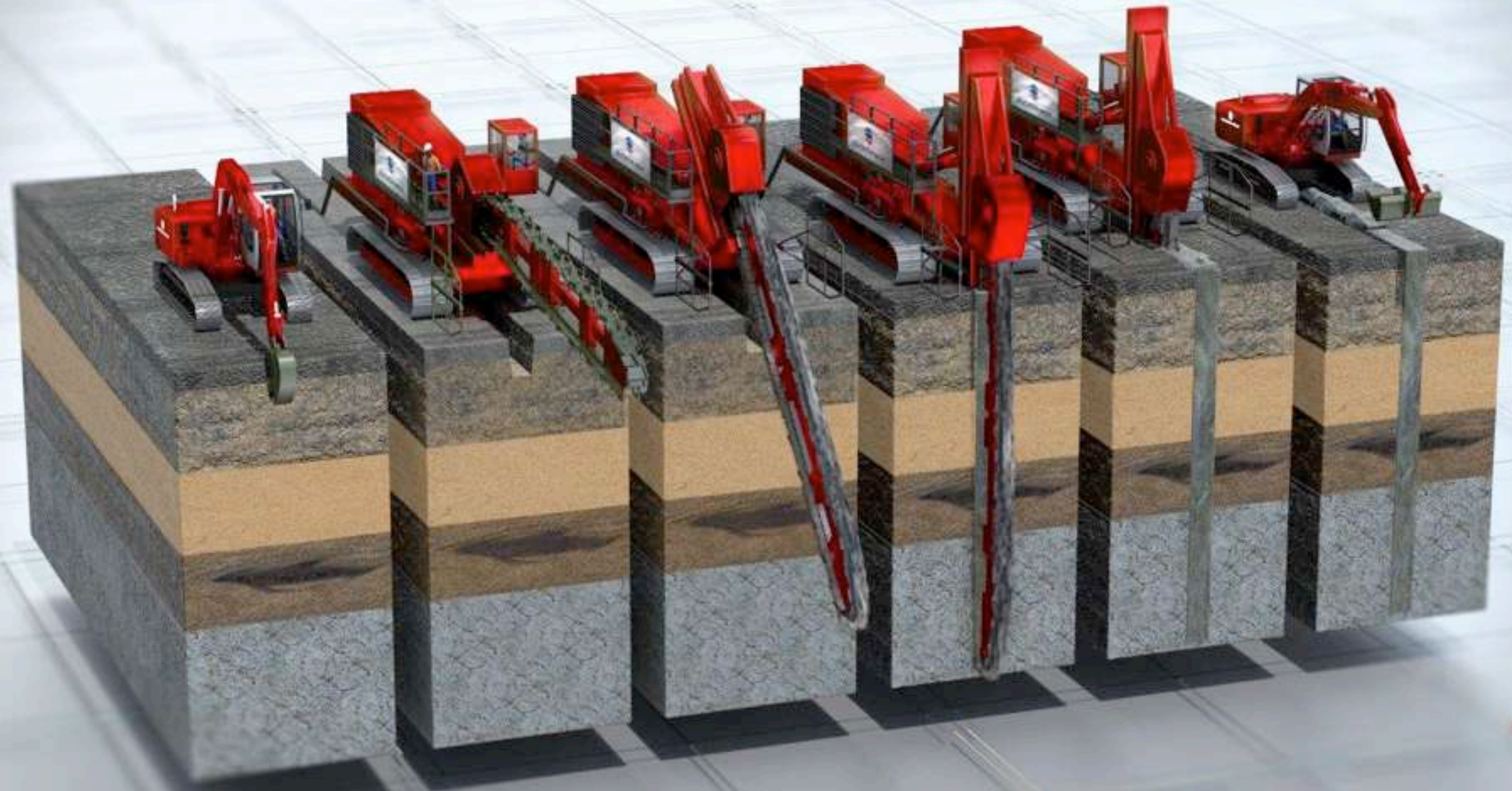
	Jet Grouting	Soil Mixing
Desintegração	Energia hidráulica (caudal de calda sob pressão)	Energia mecânica (braços cortantes)
Geometria	Incerta, diâmetro limitado pela energia	Conhecida, diâmetro limitado pela ferramenta mecânica
Quantidade de produtos sobrantes	Grande	Reduzida
Riscos de Sobrepressão	Possibilidade de sobrepressões (por obturação da saída de calda) provocando a expansão do terreno	Praticamente nulos
Características (Rc, K)	Função do caudal e do terreno	Função do caudal e do terreno

Tipos de tratamento do terreno por desintegração e execução da mistura com ligante

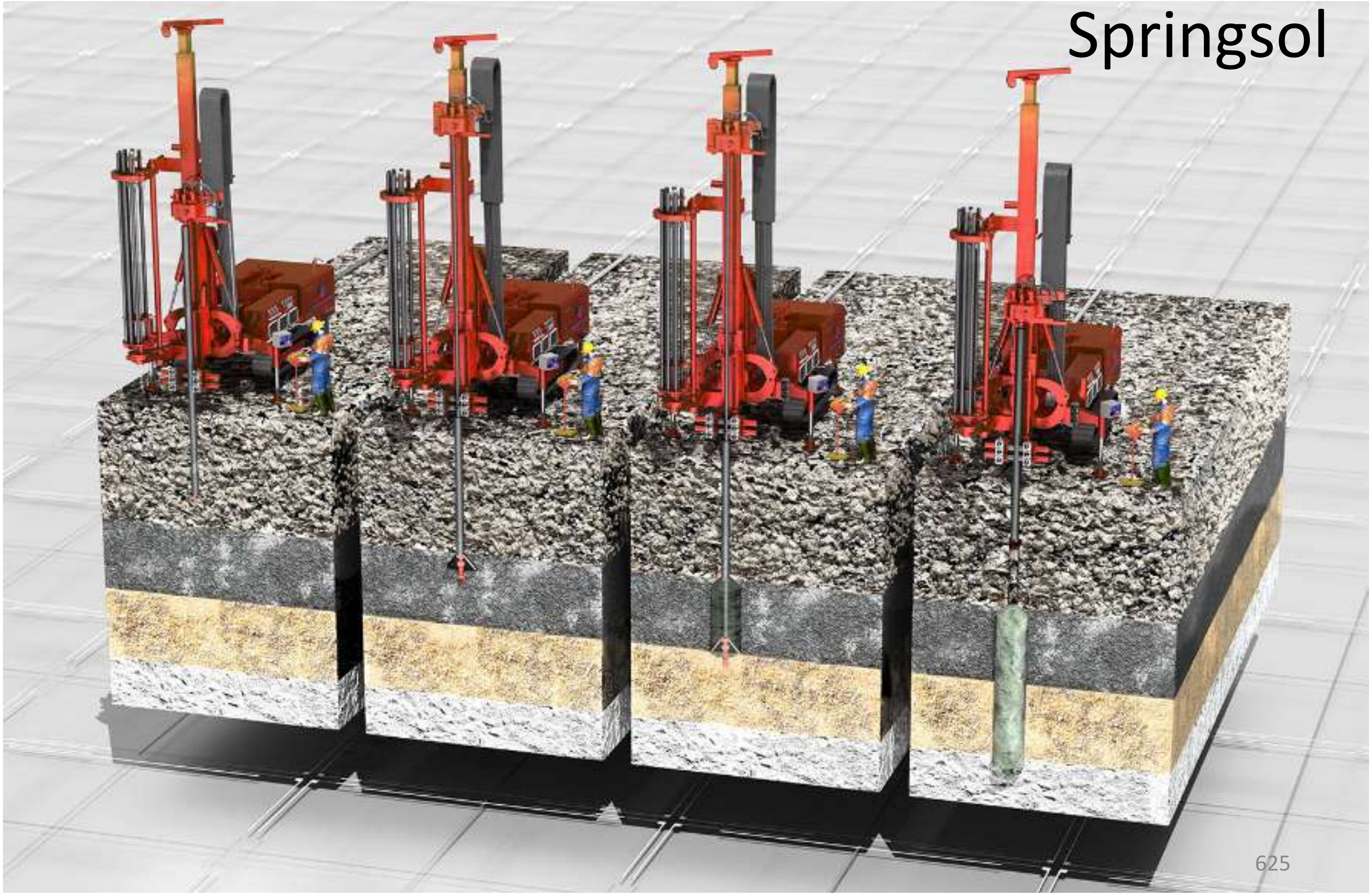
Colmix

CSM
Geomix

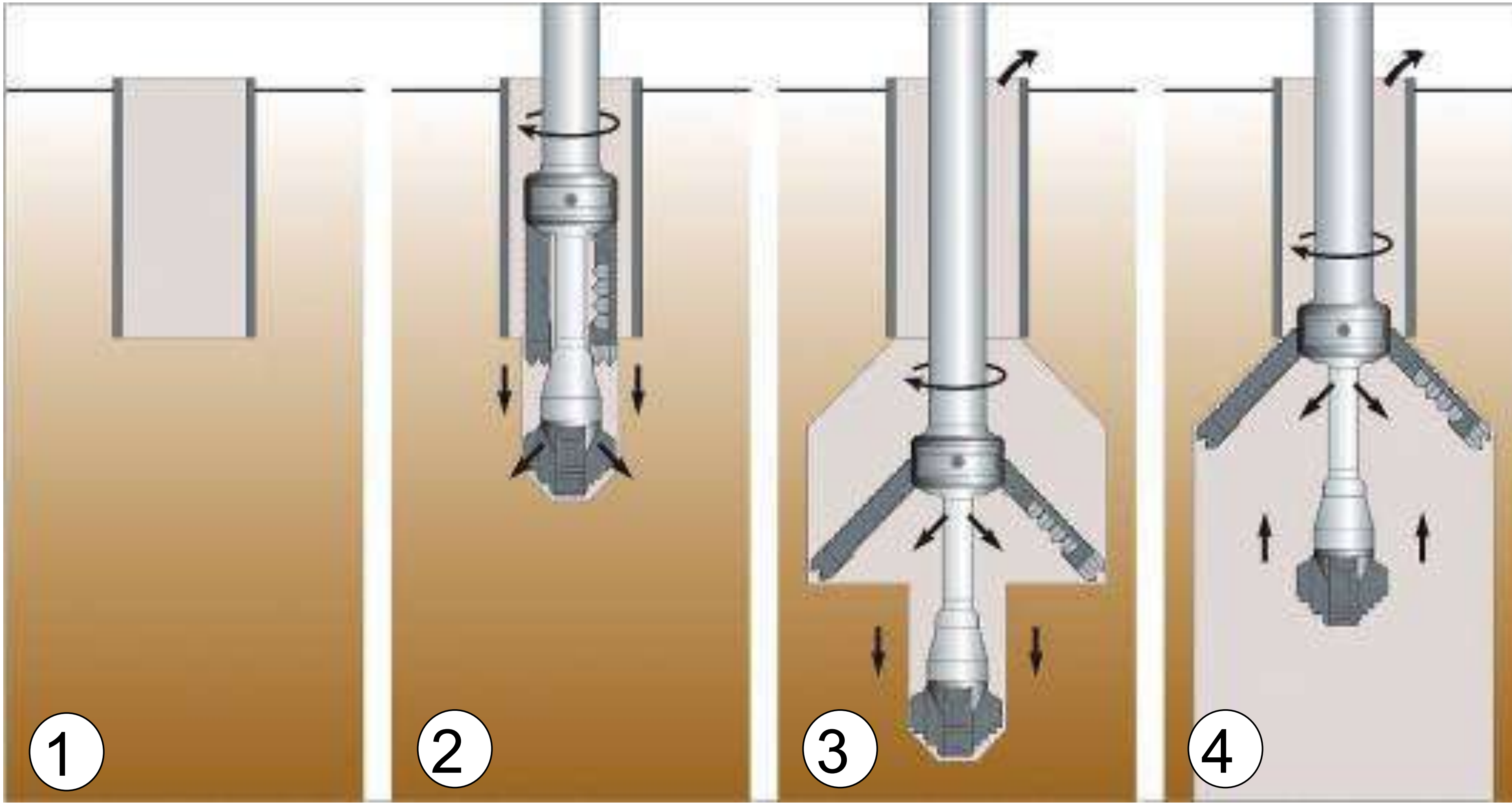
Trenchmix



Springsol



Procedimento SPRINGSOL.



Inclusões semi-rígidas. Colunas Springsol.

Classificação do Springsol dentro dos métodos de Soilmixing:

- Forma de aplicação do ligante: (Wet), mistura por via húmida com calda de cimento;

- Método de mistura: Eixo vertical rotativo com aletas na extremidade inferior das varas;

- Ponto de inserção do ligante no extremo inferior

	Métodos de soil-mixing de ejecución in situ.					
Conglomerante en polvo o en lechada	Mezcla en seco (conglomerante en polvo)	Mezcla en húmedo (conglomerante mezclado con agua en forma de lechada)				
Desestructuración mecánica o con jet	Mezclado mecánico				Mezclado mecánico + Jet	Mezclado por Jet
Punto de mezclado del conglomerante	En el extremo del eje perforador		A lo largo del eje perforador		En el extremo del eje perforador	
Ejemplos, Denominaciones representativas, Origen	-DJM Assoc (Japón), -Nordic Method (Suecia, Finlandia), -TREVIMIX (Italia), -SMM: Mass stabilisation (Japan, USA)	-CDM Assoc (Japón), -CSCC (Japón), -SSM (USA), -KS (USA, Europe), -MECTOOL (USA), -SMM Mass Stabilasation (Japón, USA), -SPRINGSOL (Francia, España)	-SMW (Japón, USA), -DSM (USA), -MULTIMIX (Italia, USA), -COLMIX Soletanche-Bachy (France), -Bauer Triple auger system (Alemania).	Zanjadoras: -FMI (Alemania), -TRENCHMIX (seco y húmedo) (Francia, Polonia, UK) . -Fresadoras "cutters" CSM, GEOMIX Francia, Alemania)	-SWING (Japón), -JACSMAN (Japón), -GEOJET (USA), -HYDRAMEC (USA), -TURBOJET (Italia)	(Fuera del alcance de este artículo) -Jet Simple, -Jet Doble, -Jet Triple, -Superjet, -JetPlus, -Crossjet
Eje rotativo, Herramienta base original	Eje rotativo vertical, Aspas en el extremo inferior del eje	Eje rotativo vertical, Aspas en el extremo inferior del eje	Eje rotativo vertical, Hélices continuas solapadas	Eje rotativo horizontal, Zanjadora de cadena de canjilones o Hidrofresa (doble tambor)	Eje vertical	Eje vertical

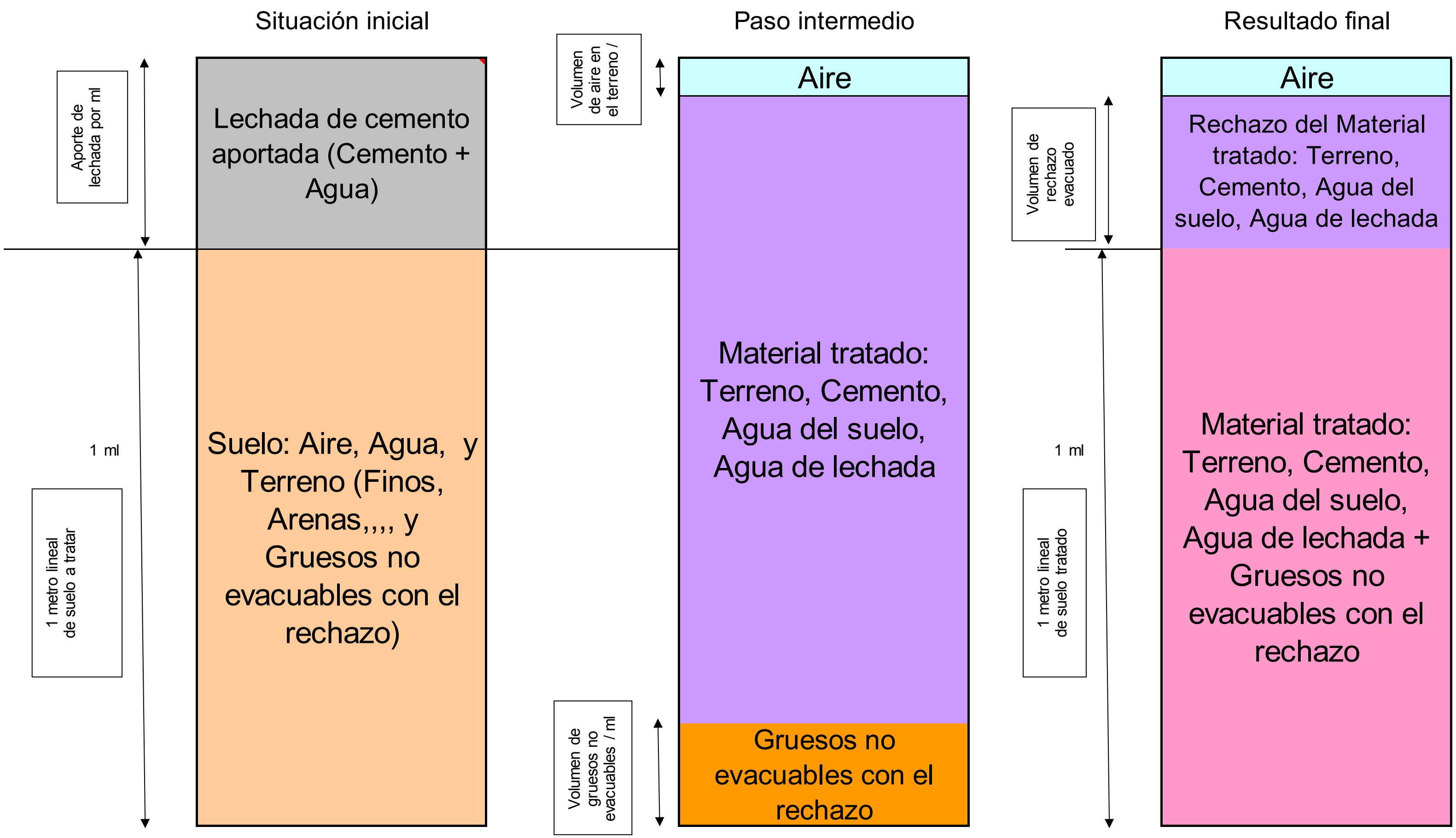
Parâmetros que determinam o processo de execução das colunas de Soilmxing

Índice de Mezcla, I_m (1/m)	$$I_m = N \cdot \frac{\omega_{rot}}{U_{perf}} \quad ;$$ • N = número de aletas de mezclado • ω_{rot} = velocidad de rotación de la herramienta (1/s) • U_{perf} = Velocidad de avance en la perforación (m/s)
Índice de incorporación, I_i (kg/m^3)	$$I_i = \frac{Wc}{Vs} = \frac{Cco \cdot Q}{\frac{\pi \cdot \Phi^2}{4} \cdot U_{perf}} \quad ;$$ • Wc = Consumo de cemento por unidad de tiempo (kg/h) • Vs ω_{rot} = Volumen tratado por unidad de tiempo (m^3/h) • Cco = kg de cemento por m^3 de lechada (kg/m^3) • Q = Caudal de lechada suministrada (m^3/h) • Φ = diámetro de la columna tratada (m) • U_{perf} = velocidad de avance de la perforación (m/h)

Balance de masas en el proceso de mezclado:

Atención!!! A tener en cuenta en las correlaciones de resistencia:

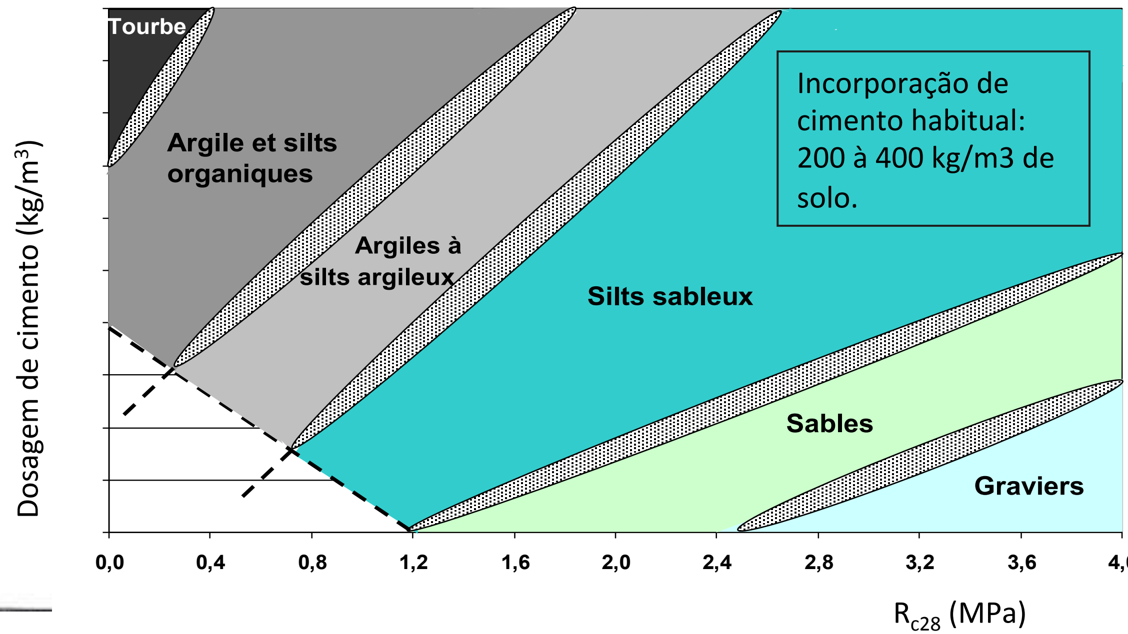
- ✓ El cemento remanente en la columna tratada, es el aportado menos el evacuado en el rechazo.
- ✓ El agua del material suelo-cemento es en parte procedente de la que aporta la lechada y la ya existene en el terreno)

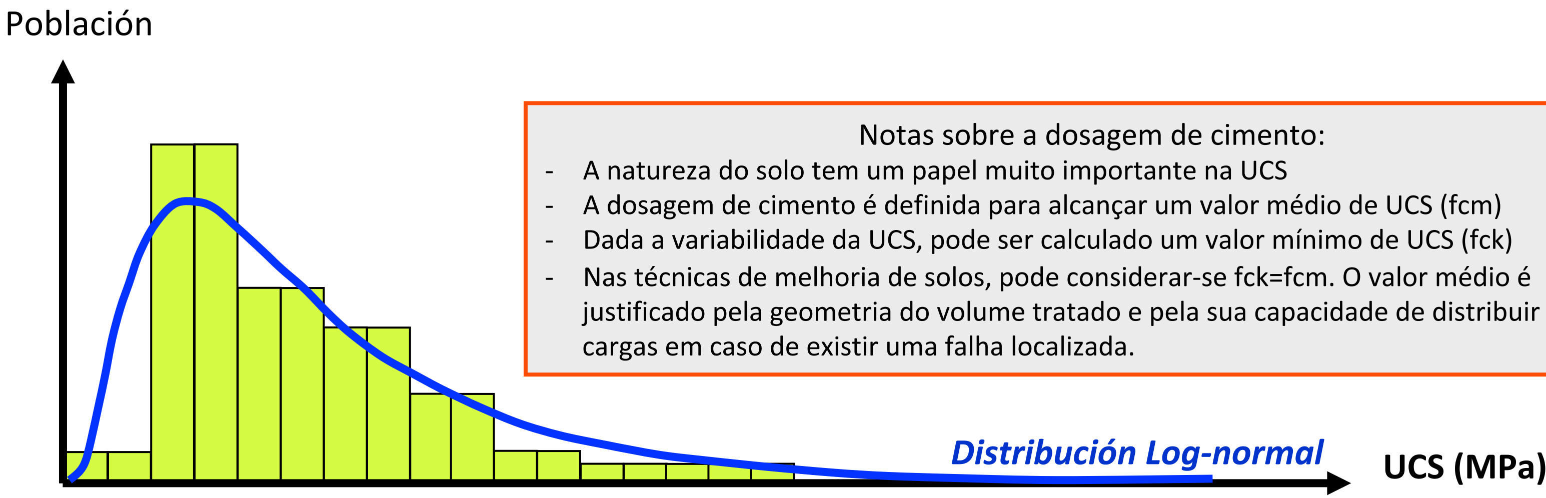


Resistência do material em função do tipo de terreno

As correlações habituais não têm em conta a influência do teor de água do terreno, pelo que devem sempre confirmar-se com ensaios.

Soil type	Cement factor, α [kg/m³]	U.C.S. 28-d q_{uf} [MPa]
Sludge	250 - 400	0.1 - 0.4
Peat, organic silts/clays	150 - 350	0.2 - 1.2
Soft clays	150 - 300	0.5 - 1.7
Medium/hard clays	120 - 300	0.7 - 2.5
Silts and silty sands	120 - 300	1.0 - 3.0
Fine-medium sands	120 - 300	1.5 - 5.0
Coarse sands and gravels	120 - 250	3.0 - 7.0





Notas sobre a dosagem de cimento:

- A natureza do solo tem um papel muito importante na UCS
- A dosagem de cimento é definida para alcançar um valor médio de UCS (fcm)
- Dada a variabilidade da UCS, pode ser calculado um valor mínimo de UCS (fck)
- Nas técnicas de melhoria de solos, pode considerar-se fck=fcm. O valor médio é justificado pela geometria do volume tratado e pela sua capacidade de distribuir as cargas em caso de existir uma falha localizada.

Produto resultante do Springsol:

- **Geometria** perfeitamente definida (garante o cumprimento do diâmetro da coluna)
- **Resistência** dependente da natureza do terreno a tratar, do seu teor de água terreno, da relação água-cimento da mistura de ligante e da dosagem de cimento resultante no terreno tratado.
- **Comportamento** semelhante ao de uma inclusão semi-rígida no terreno não tratado, podendo o terreno tratado ser estudado como um todo através de propriedades homogeneizadas, ou considerar-se a interação individual da coluna com o terreno envolvente.
- **Evolução da resistência** do material solo-cimento mais lenta que argamassas e betões e continua a ser incrementada para além dos 28 dias, sendo habitual falar-se de resistências de 90 dias.
- **Permeabilidade** muito baixa, entre 1×10^{-7} e 1×10^{-9}m/s sendo importante criar barreiras impermeáveis ao fluxo da água no terreno através de colunas sobrepostas.

Estudio de las características del material durante la construcción

Propiedades del material (Rc, permeabilidad, ...) Tomadas después del endurecimiento

Permeabilidade:
1×10^{-7} a 1×10^{-9}m/s

Tipo de solo tratado	Rc 90/ Rc 28	E/R_{c28}
Coerente	**1.3 – 1.5**	**100 – 300**
Granular	**1.5 – 2.0**	**300 – 600**

RODIO-KRONSA CÁLCULO SPRINGSOL

1.- Composición del terreno

Peso especifico de los Finos y evacuables,	Dae =	27,1 kN/m³	2762 kg/m³	
Densidad aparente,	Dap =	20,0 kN/m³	2039 kg/m³	
Densidad seca,	Dsec =	18,0 kN/m³	1835 kg/m³	
Índice de poros,	e =	50,56%		
humedad,	e_w = 30,11%	w = 11,1%	Sr = 59,6%	
huecos vacios (aire)	e_a = 20,44%			
Contenido de gruesos (no evacuables)	gruesos =	20% (no pasa tamiz)		
Concentración de agua en 1 m³ de suelo;	Aco =	2,22 kN/m³	227 Kg/m³	

2.- Dosificación de la lechada de cemento

Peso del agua/cemento; (Pa / Pc)	100	100	Kg	
Relación agua / cemento:	K =	1,00		
Peso especifico cemento:	Dcem=	31 kN/m³	3160 kg/m³	
Densidad de lechada:	Dl =	15,12 kN/m³	1541 kg/m³	
Kg de cemento en 1 m³ de lechada:	Cco =	7,56 kN/m³	771 kg/m³	

3.- Caudal de aporte de lechada en función de velocidad de perforación

Velocidad de Perforación,	Uperf =	30,00 cm/min	3,33 min/m
Giro en la perforación (50rpm aconsejadas),	ωrot=	60 rpm	
Número de aspas,	N =	2	6,0 mm/rev
Índice de mezcla,	Imix =	333 cortes/m	3,0 mm de rebanada
Diámetro de Columna,	Diam =	40 cm	0,40 m
Volumen de 1ml de columna (sección)	Vo =	0,126 m³/ml	
Índice de incorporación (dosificación aportada)	Ii =	220 kg/m³	(cemento/m³ de suelo a tratar)
Caudal a inyectar,	Q =	10,8 l/min	

Por metro lineal de columna:

kg Cemento por metro lineal	Do =	27,6 kg/ml
Volumen introducido de lechada,	Vi =	35,9 litros/ml

3.- Composición del rechazo

Volumen evacuado,	Vr =	18,8 litros/ml	5,6 litros/min
Densidad del rechazo,	Dr =	20,3 kN/m³	
Velocidad ascensional del rechazo;	Uar =	4,49 cm/min	

4.- Composición de material en columna (suelo tratado)

Gruesos no evacuados

Contenido de cemento en el suelo tratad

Minimos ratios de mezcla Imix = N*Uperf/ωrot, segú

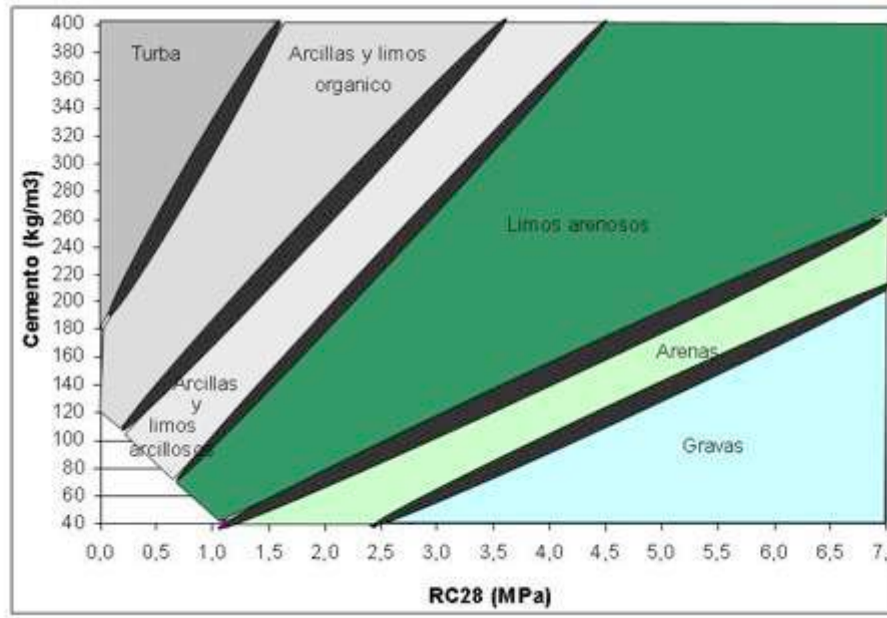
Imix = [cortes/metro]

Determinação da soilmixing - Springsol:

Ponderação das massas para estimar a dosagem final de cimento na coluna tratada

Índice de Incorporação

(em função do tipo de solo e da resistência final requerida)

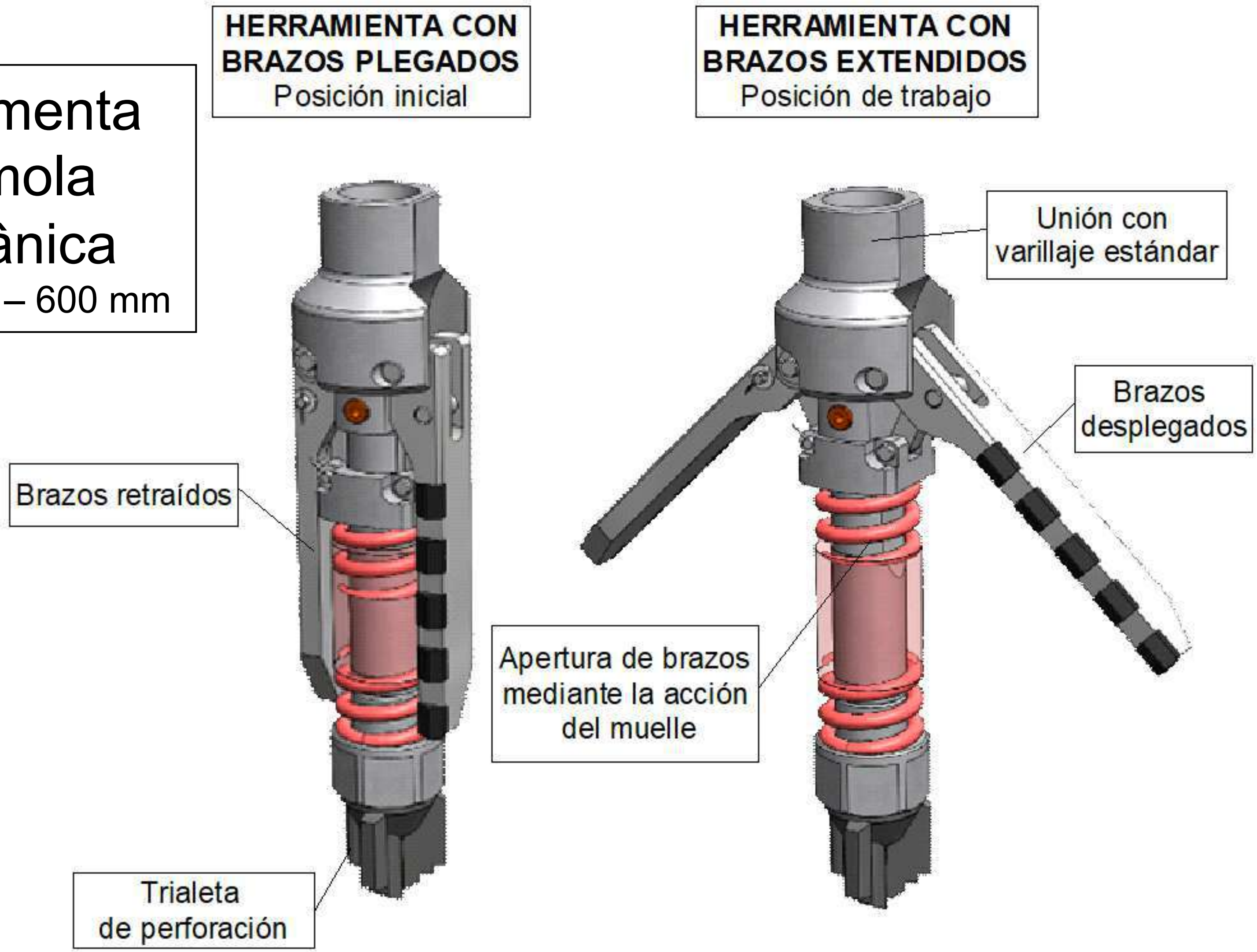


Índice da Mistura:

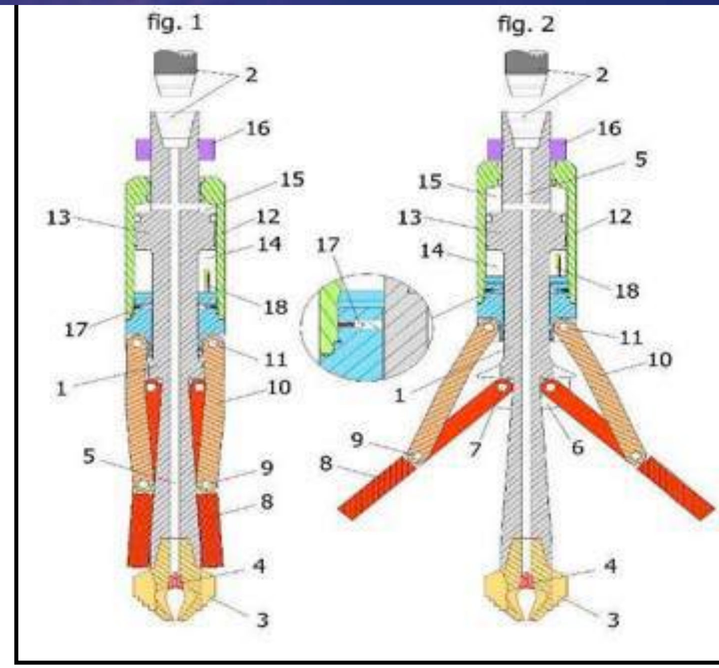
Mínimos ratios de mezcla Imix = N*Uperf/Wrot, según tipo de suelo			Granular	Cohesivo
	Imix =	[cortes/metro]	100 a 150	200 a 250

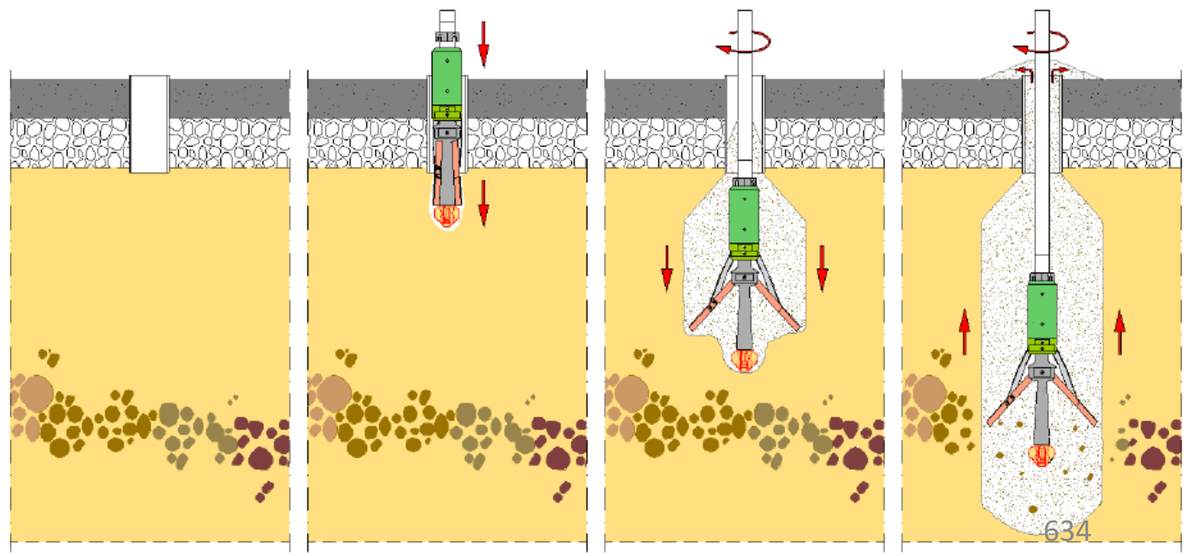
Procedimento SPRINGSOL. Tipos de ferramentas

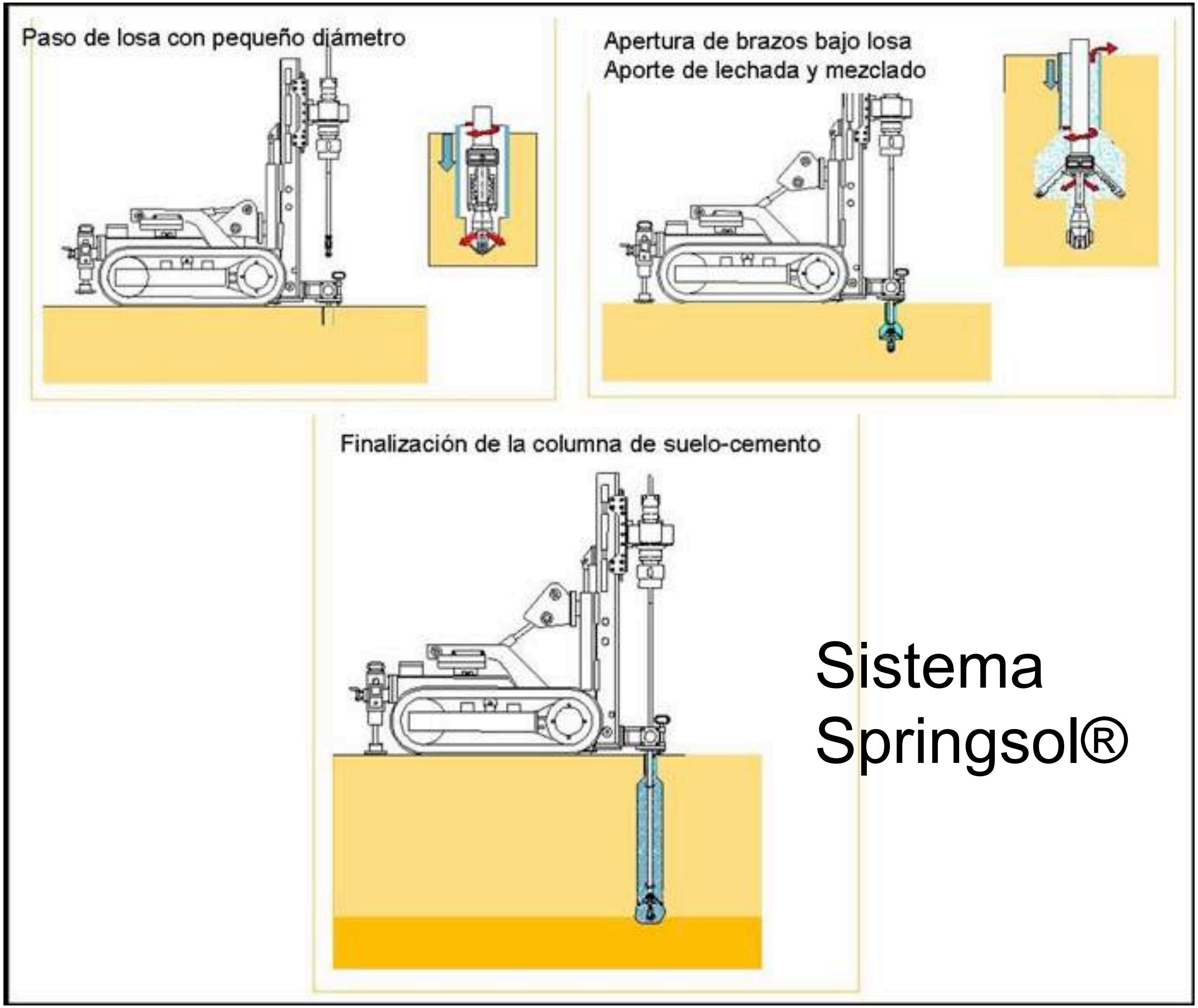
Ferramenta de mola mecânica
Diâm. 400 – 600 mm



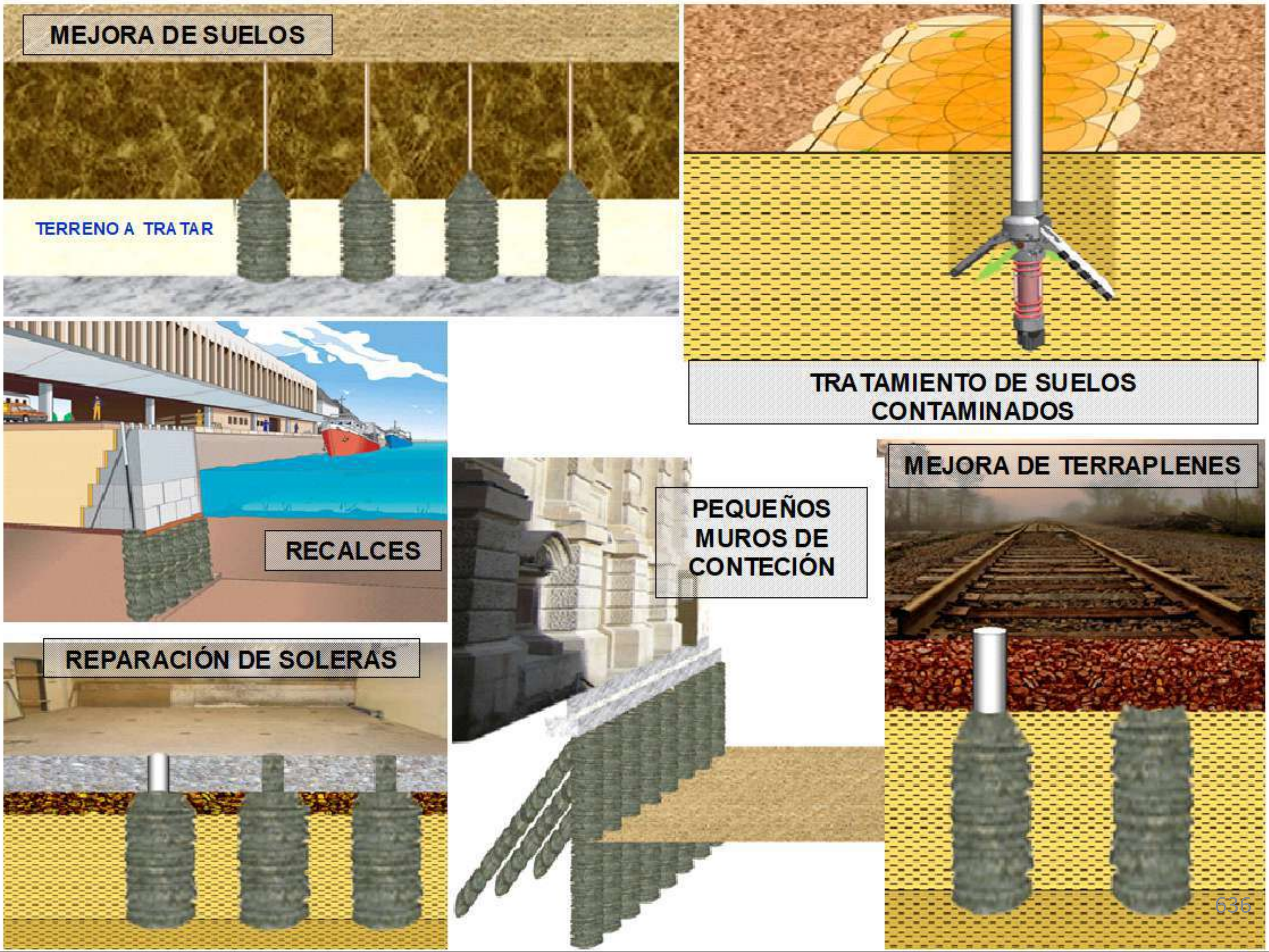
Ferramenta Springsol
de mola pneumática
Diâm. 400 -600mm



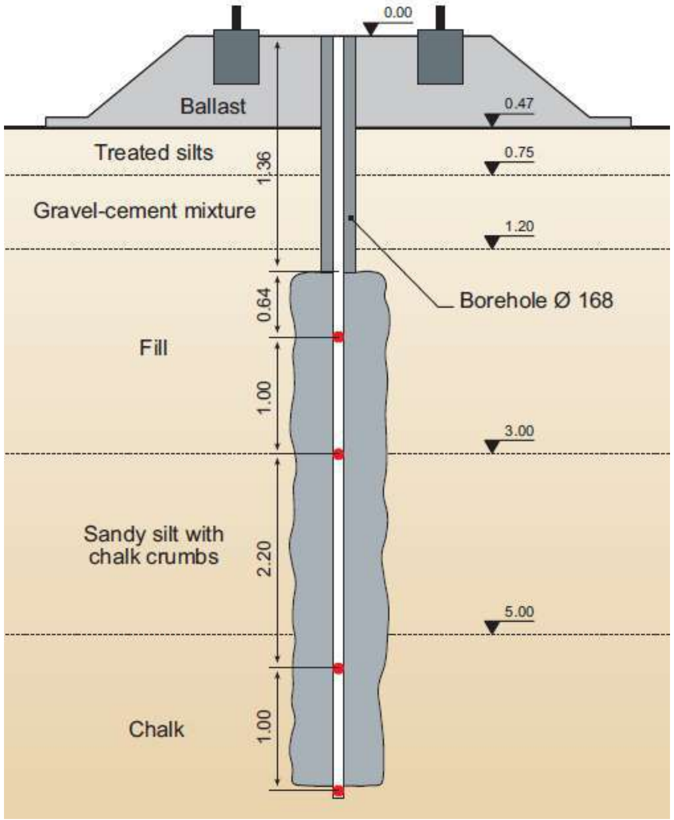




Sistema Springsol®


MEJORA DE SUELOS
TERRENO A TRATAR
TRATAMIENTO DE SUELOS CONTAMINADOS
RECALCES
PEQUEÑOS MUROS DE CONTECIÓN
MEJORA DE TERRAPLENES
REPARACIÓN DE SOLERAS

Springsol® aplicado no tratamento de aterro ferroviário como inclusão rígida



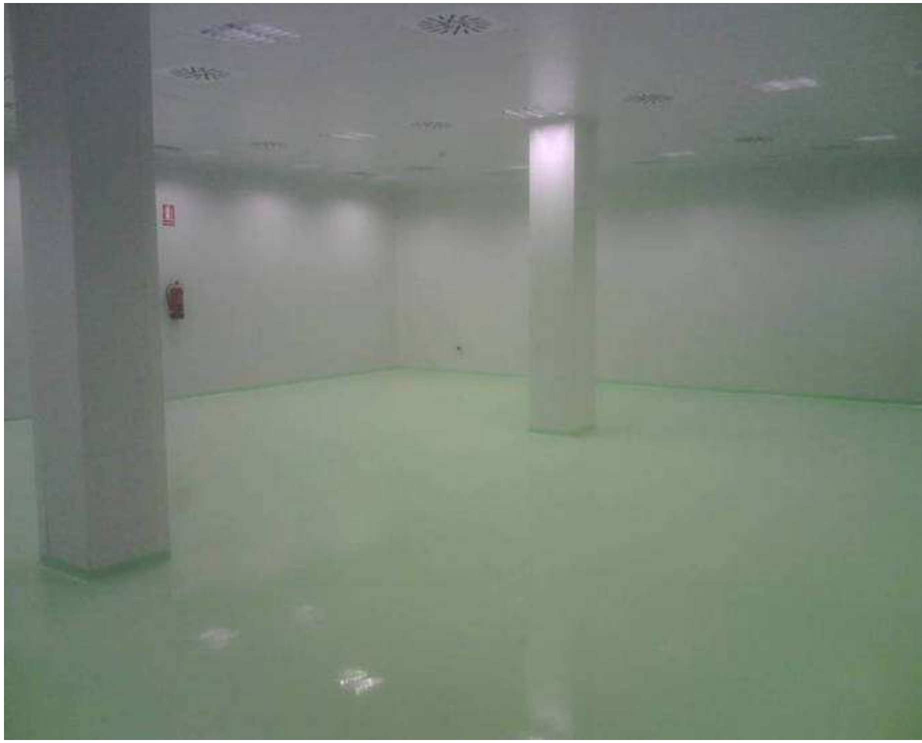
Execução entre travessas

Sem contaminação da camada de balasto

Springsol® aplicado no tratamento de recalce de lajes

Springsol® aplicado no tratamento de recalce de lajes

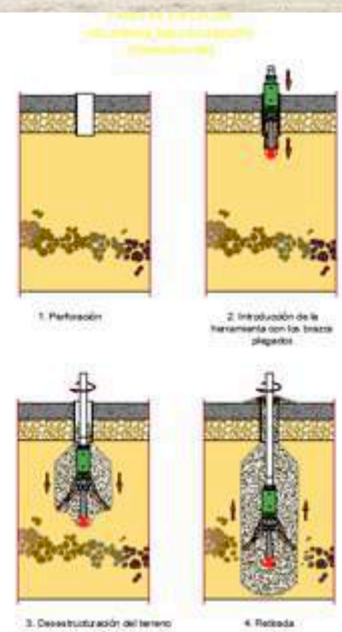
Trabalhos concluídos no interior das salas intervencionadas



Springsol® aplicado no tratamento de soleira de um Centro Comercial

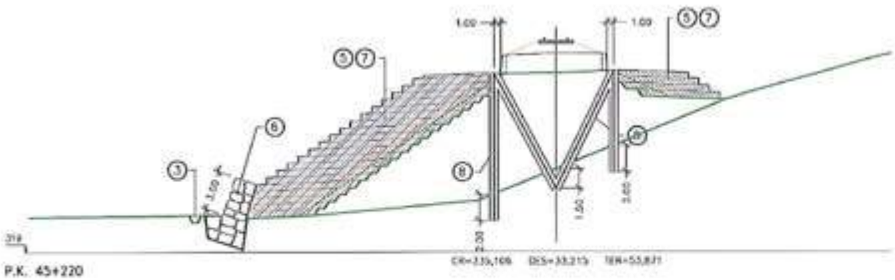
Decathlon Puerto de Santa María (Cádiz)

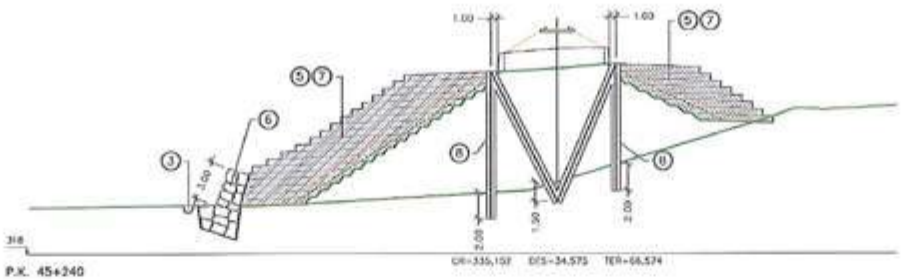
Trabalhos de recalce, mantendo a loja em funcionamento

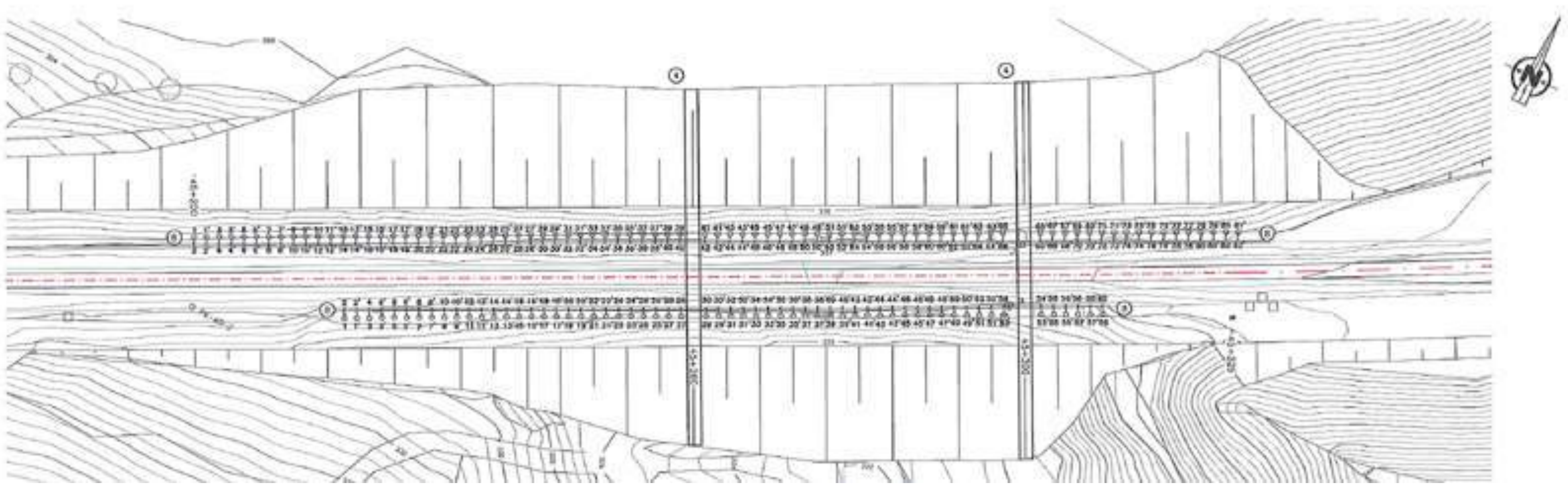


Springsol® aplicado no tratamento de aterro

Aterro na linha férrea de Linares-Almería

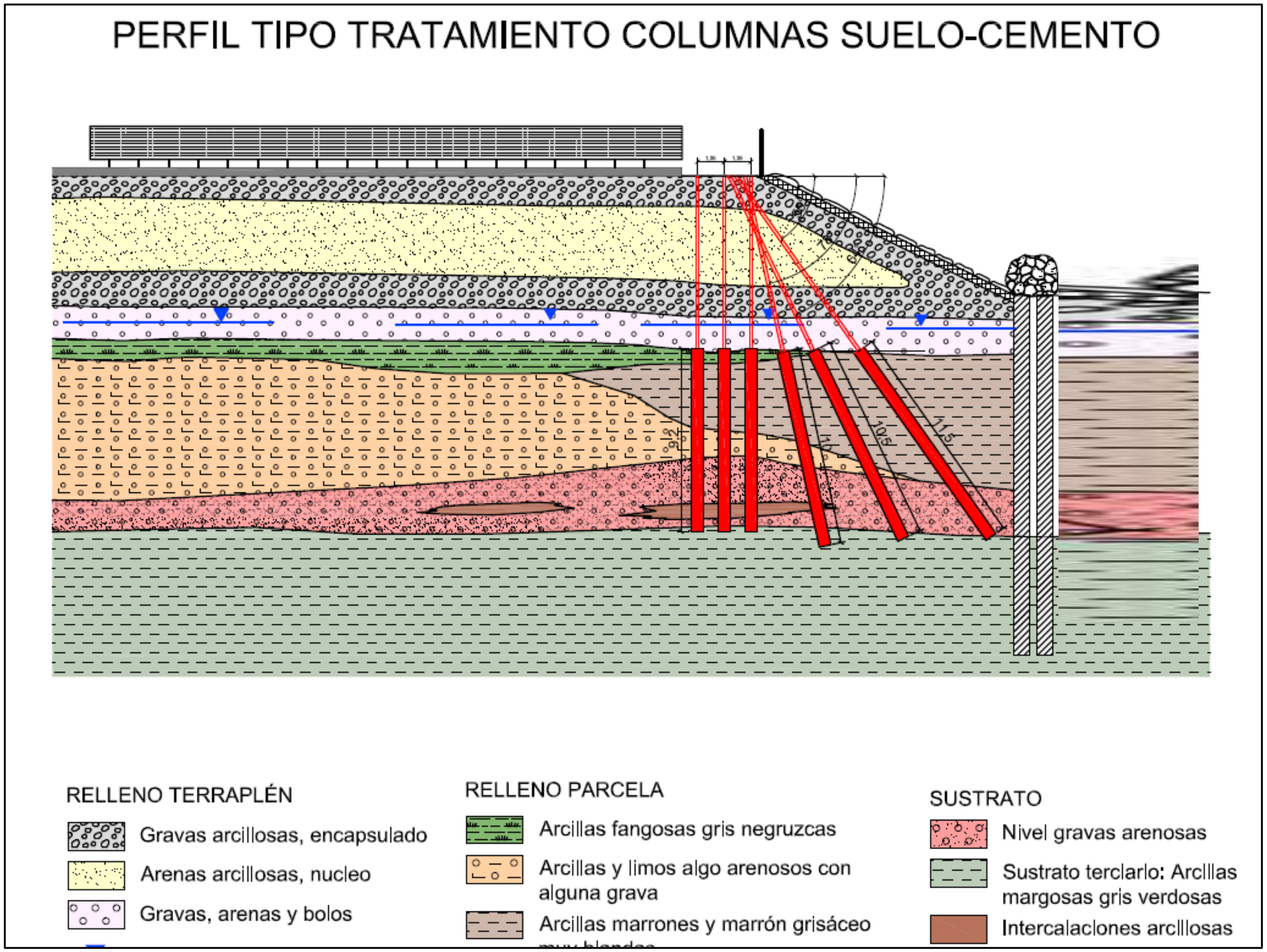




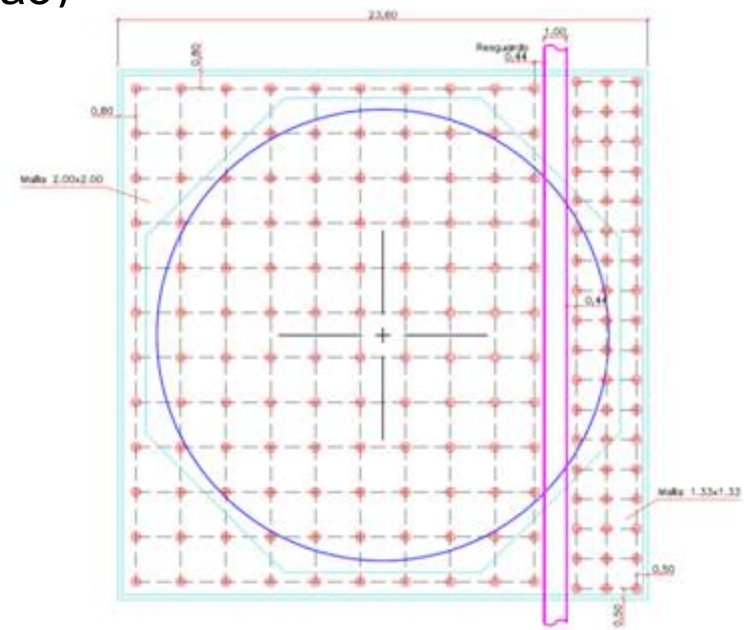


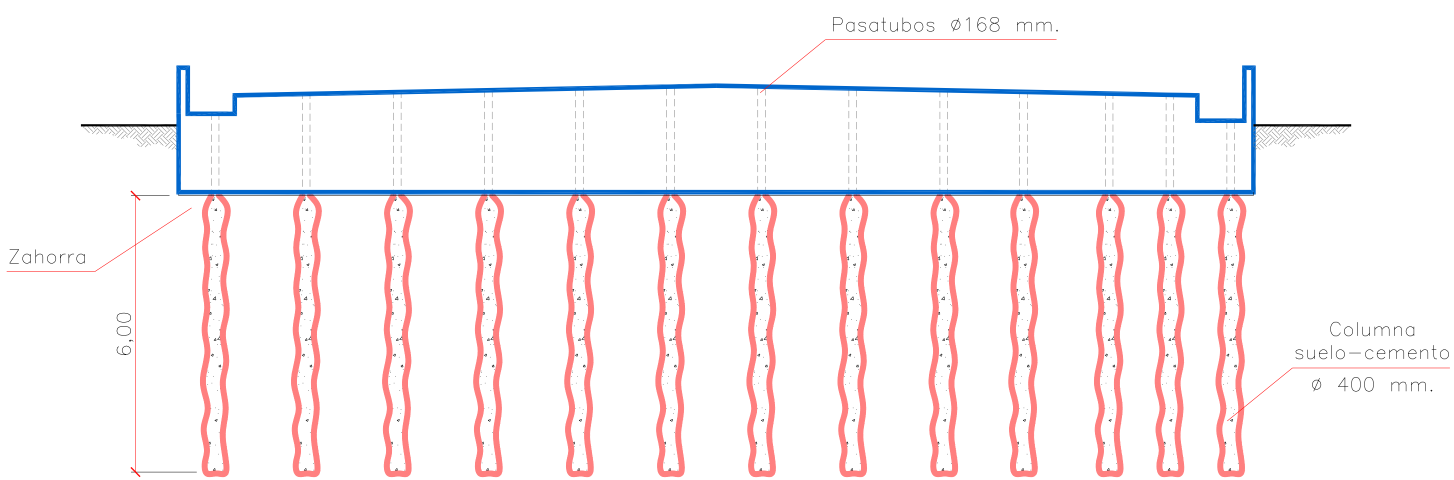
Springsol® aplicado no tratamento de talude de um aterro instável

Aterro numa plataforma fotovoltaica em Sevilha

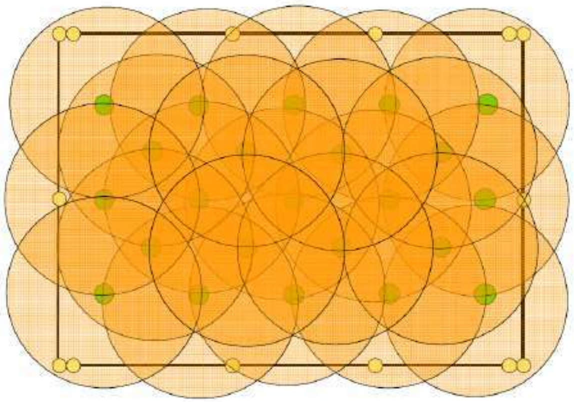


Springsol® aplicado no tratamento de fundações de um tanque de ácido sulfúrico (Bilbao)





Springsol® aplicado no tratamento de maciço e impermeabilização do terreno



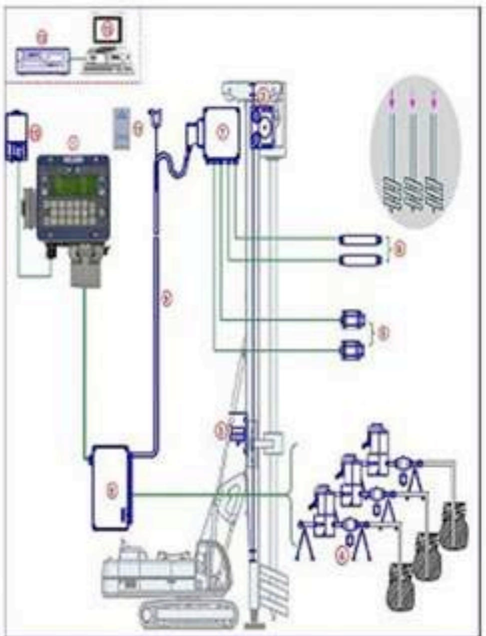
Springsol® em Lisieux , Francia (Ano 2012) para tratar solo contaminado

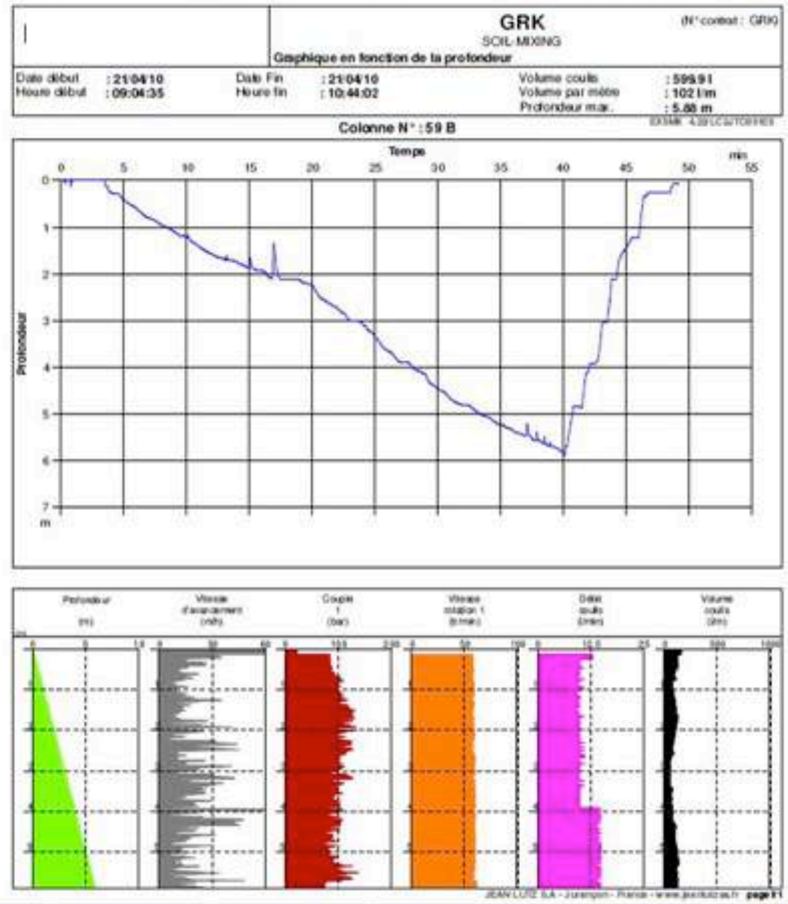
Springsol® aplicado no tratamento de impermeabilização e consolidação da frente de uma escavação subterrânea (Singapura)

Equipamento necessário para a execução de colunas de solo-cimento Springsoil

Sistema de monitorización y registro de parámetros para la recopilación de datos y posterior tratamiento informático,para cada columna.

INSTRUMENTACIÓN Y CONTROL

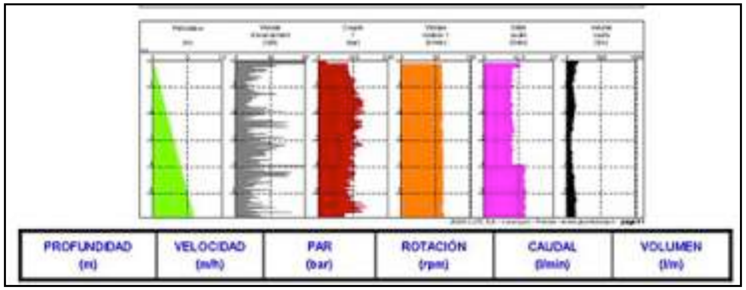




PROFUNDIDAD (m)	VELOCIDAD (m/h)	PAR (bar)	ROTACIÓN (rpm)	CAUDAL (l/min)	VOLUMEN (l/m)


12/03/2009

Vantagens do Soilmixing, relativamente a outros métodos de tratamento por injecção



- **Economia,** para a mesma finalidade, os consumos de ligante são muito inferiores aos consumos requeridos noutras técnicas. Em particular, relativamente à técnica de Jet-Grouting, para se conseguir a mesma coluna de solo-cimento, os consumos podem ser da ordem dos 25%.
- **Sustentabilidade**, (utiliza o próprio solo como material de construção). Diminuição de consumo de material e, por exemplo, relativamente ao Jet-Grouting verifica-se uma redução dos resíduos sobrantes.
- **Geometria conhecida com exatidão,** ao contrário de outras técnicas de tratamento por injecção, a geometria do elemento tratado é conhecida. Nas injecções de calda sob pressão e na técnica de jet-grouting, o diâmetro de afectação é sempre uma incógnita.
- Possibilidade de **registo de parâmetros** de execução e **automatização** dos procedimentos.
- Controlo dos **reduzidos resíduos** gerados através de sistemas de captação desenhados para esse fim.

Biocementation by Biocalcis, from design to site implementation

Annette Esnault Filet[1] & Jorge Paulino[2]

1 : annette.esnault@soletanche-bachy.com

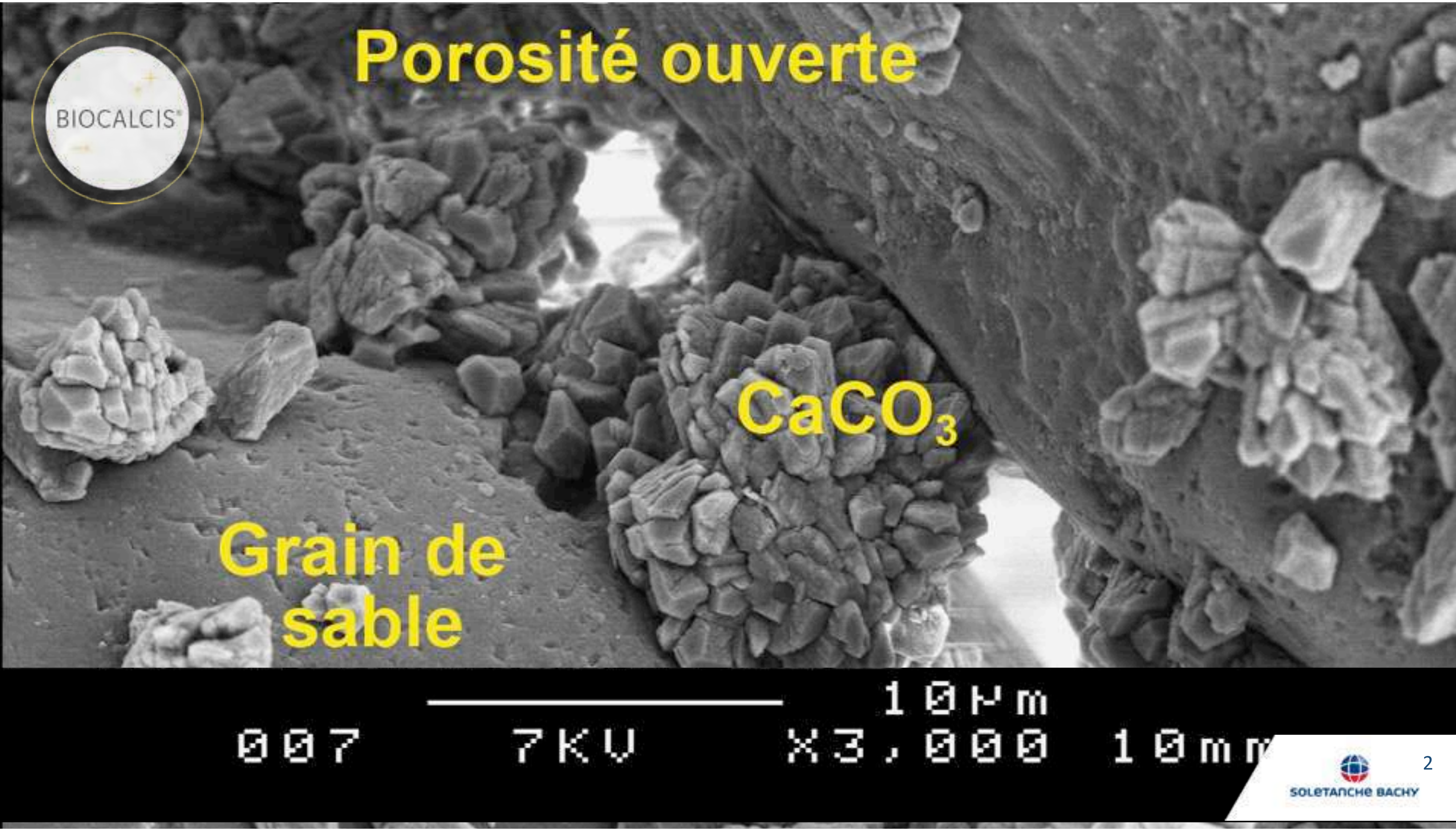
2 : jorge.paulino@rodio.pt

SOLETANCHE BACHY

RODIO

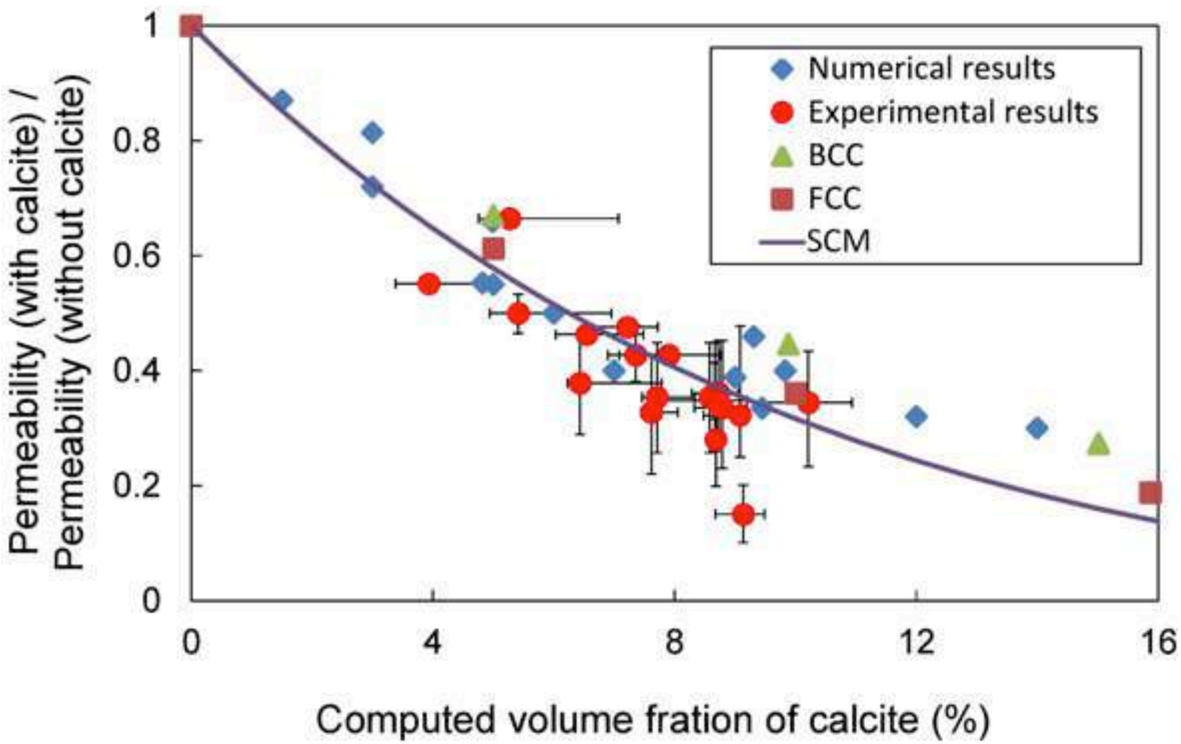
Photo: C Eeckhout, 2008

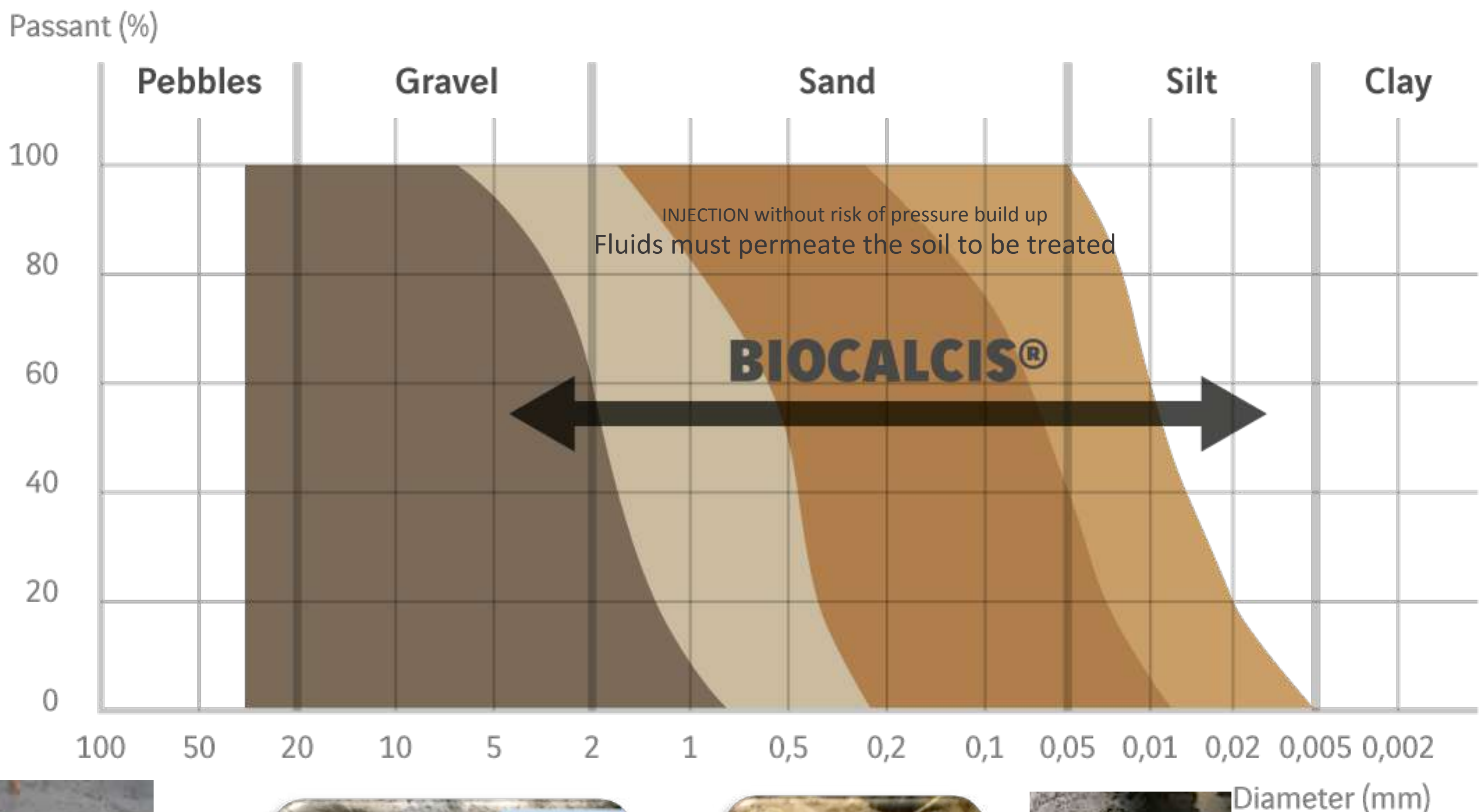
SOLETANCHE BACHY 1



SOLETANCHE BACHY

Example of K vs Calcite content




Passant (%)
Pebbles
Gravel
Sand
Silt
Clay
100
80
60
40
20
0
INJECTION without risk of pressure build up
Fluids must permeate the soil to be treated
BIOCALCIS®
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
0,01
0,02
0,005
0,002
Diameter (mm)


Tube d'injection C

Anti-liquefaction soil treatment

Erosion control (suffusion – internal erosion)

Maritime structures – quay walls

Restoration of reinforced earth structures

Foundations

Embankments

Old masonry restoration

Photo: C Eeckhout, 2008

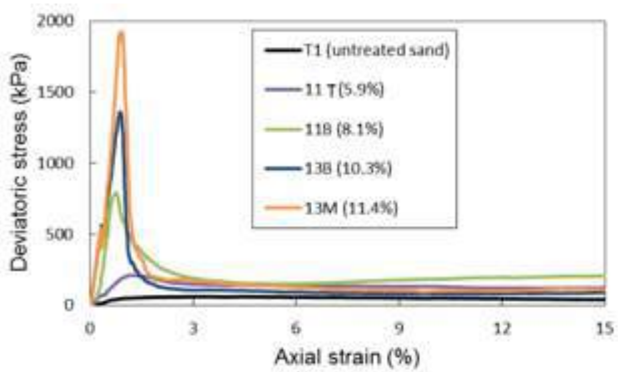
LIQUEFACTION

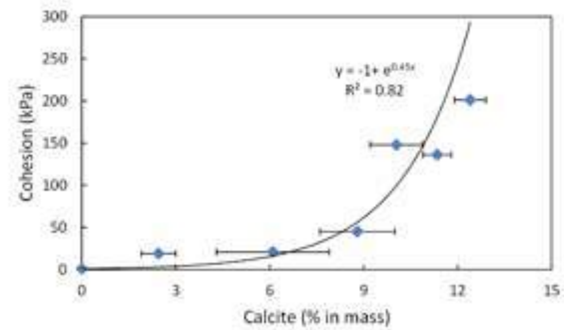
Niigata, Japon, 1964
Magnitude 7.5
Richter

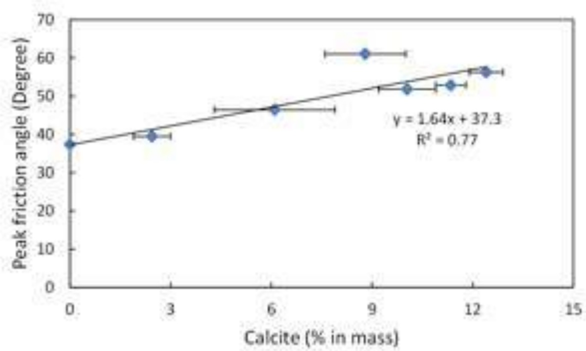
Séisme de San Fernando 1971

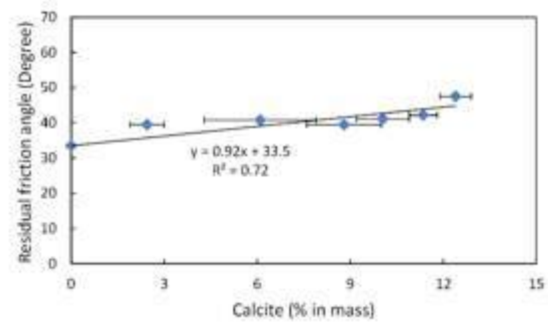
Séisme de Tohoku 2011

MECHANICAL PROPERTIES OF CALCIFIED MATERIAL (examples)







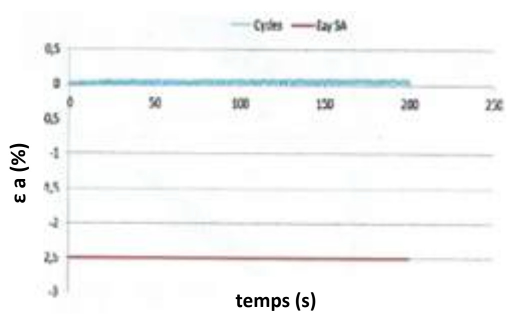


MECHANICAL PROPERTIES

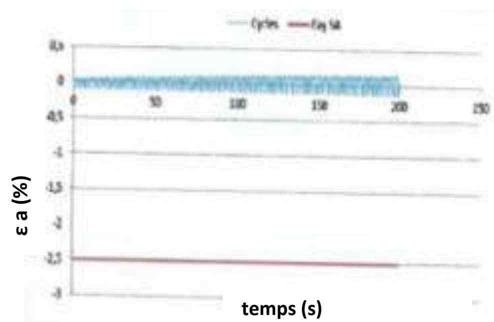
BOREAL PROJECT : application on dykes (EDF, CNR)

- Mechanical properties enhanced by the treatment (modulus, cohesion,…)
- Improvement of liquefaction curve
- Laboratory trials :
  - No liquefaction occurs even for low calcite levels

σ_c=50kPa - **CSR=0,35**

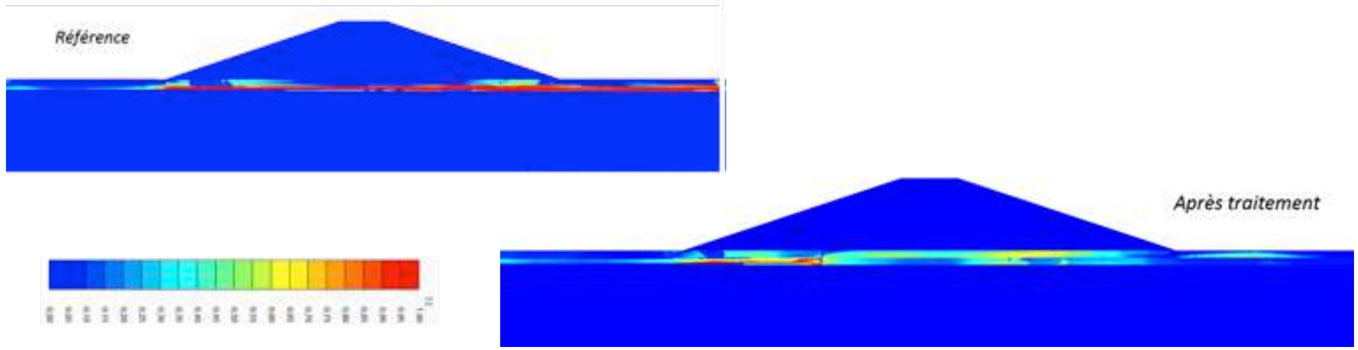


σ_c=50kPa - **CSR=0,60**

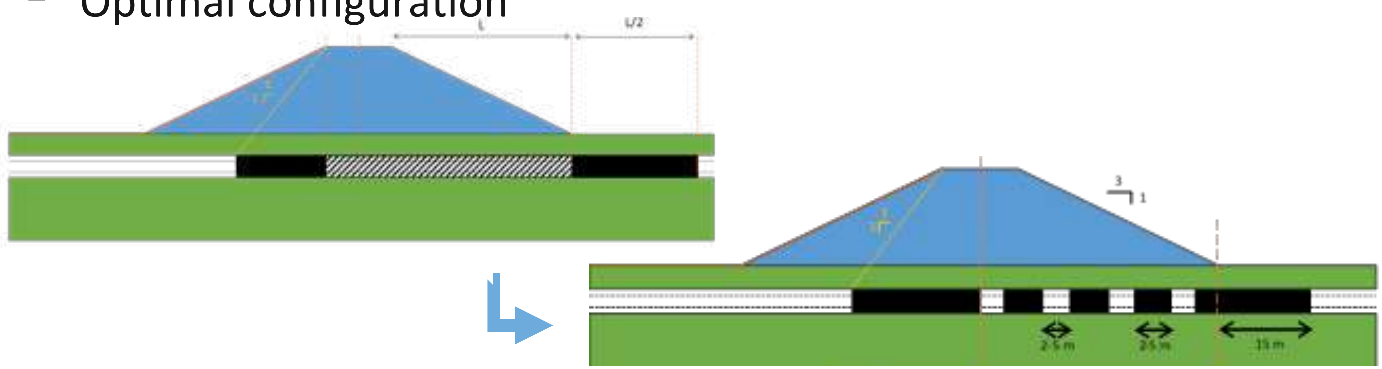


BOREAL PROJECT : application on dykes (EDF, CNR)

- Liquefaction level



- Optimal configuration



(Examples)

Anti-liquefaction soil treatment

- Commercial targets:
  - existing structures: « update » following new rules and values for seismic design (i.e. Eurocode)
  - new structures

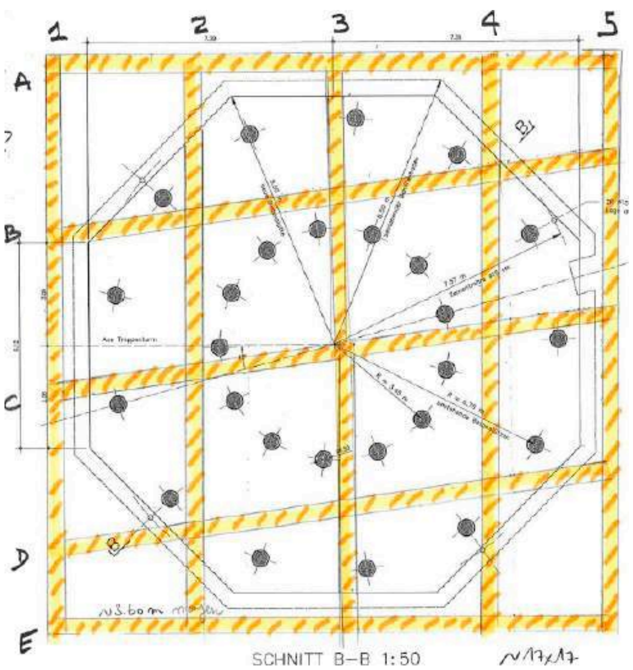
- Usual (standard) solutions:
  - Geomix or Trenchmix (soil-mixing) caissons
  - Jet Grouting
  - Stone columns
  - Various soil improvement techniques (vibro-compaction, traditional compaction)
  - …

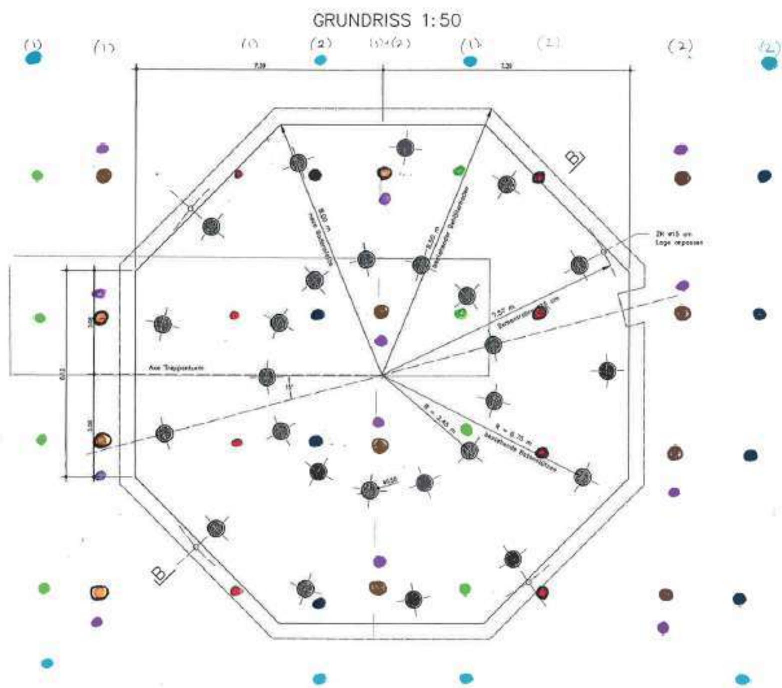
Example : Switzerland – Industrial Site

- Anti-liquefaction treatment under existing silos constructed on deep foundations (piles) → major constraints: very small working space (reduced height) &
- presence of deep foundations and
- underground cables and pipes
- Treatment of « Alluvions Modernes »:
- . between -3.5m et -9.5m
- . surface 16m x 16m
- Design office defined soil parameters to be
- obtained:
- . cu and / or UCS

Example : Switzerland – Industrial Site

- « Soil Mix Caissons » VS « Biocalcification »





Anti-liquefaction soil treatment

- Advantages compared to usual (standard) solutions :

  - Homogenous soil treatment : “mass” treatment

  → Values of cu / UCS to be obtained are smaller than those needed for soil mix solutions (as those are discontinuous)

  - No piling/excavation tool

  → Very small diameter injection boreholes : reduced risk of damage to the existing foundations and underground cables and pipes & limited damage (= deconstruction) of existing base slab

Design approach & target properties of treated ground

Soil is transformed in coherent soil mass characterized by its unconfined compression strength (UCS)

- **Estimation of mechanical characteristics based on correlations between UCS and undrained cohesion, limit pressure, modulus**
- **Hydraulic characteristics:**

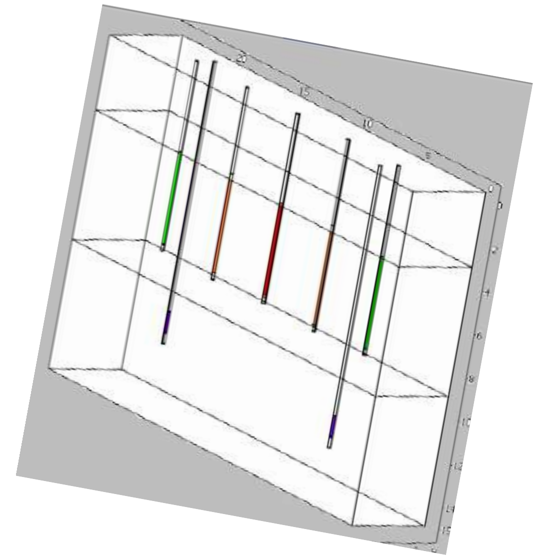
UCS ≤ 500 kPa → no significant change in permeability

UCS ≥ 1000 kPa → reduction in permeability but due to cost of high resistance injection this application has not been targeted for now

Target properties of treated ground : design will define value of UCS needed for required soil resistances

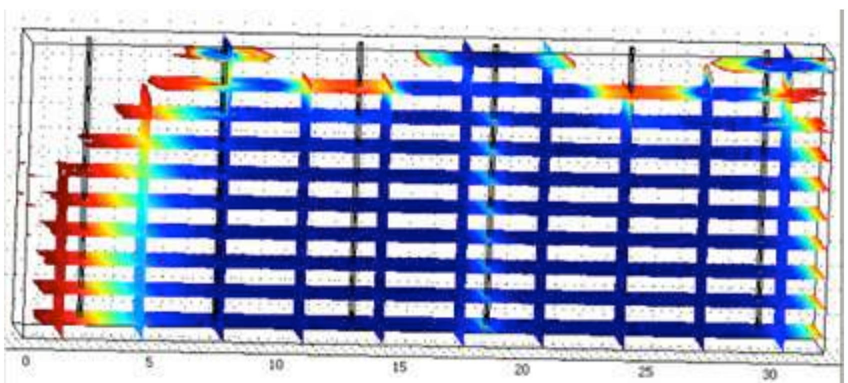
Then depending on the target UCS value and soil characteristics (porosity, density) the process will be adapted

Implementation design



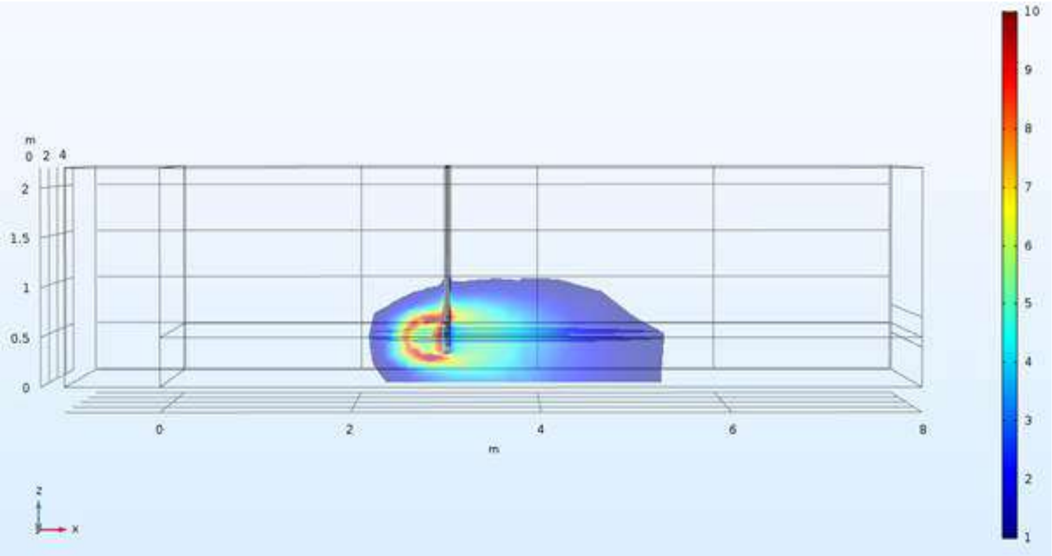
Specific Modelling tools

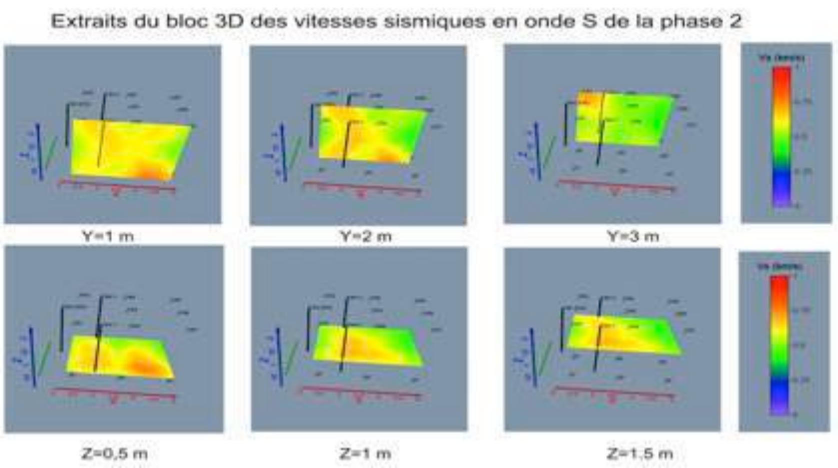
- **Hydraulic Modelling** - Couple Solute transport with Darcy's law (*ex COMSOL Multiphysics*) :



Optimisation of grouting grid and injection parameters according to K, Porosity, etc.

A3 test : Injection in sandy gravels





Photograph courtesy VSF (NL)

Some examples from 2005 to 2018

THANK YOU FOR YOUR ATTENTION

SYNTHESE DES RESULTATS POST TRAITEMENT

Extrait film CNR

ANCHORED HIGH PERFORMANCE TURF REINFORCEMENT MAT FOR SLOPE STABILIZATION

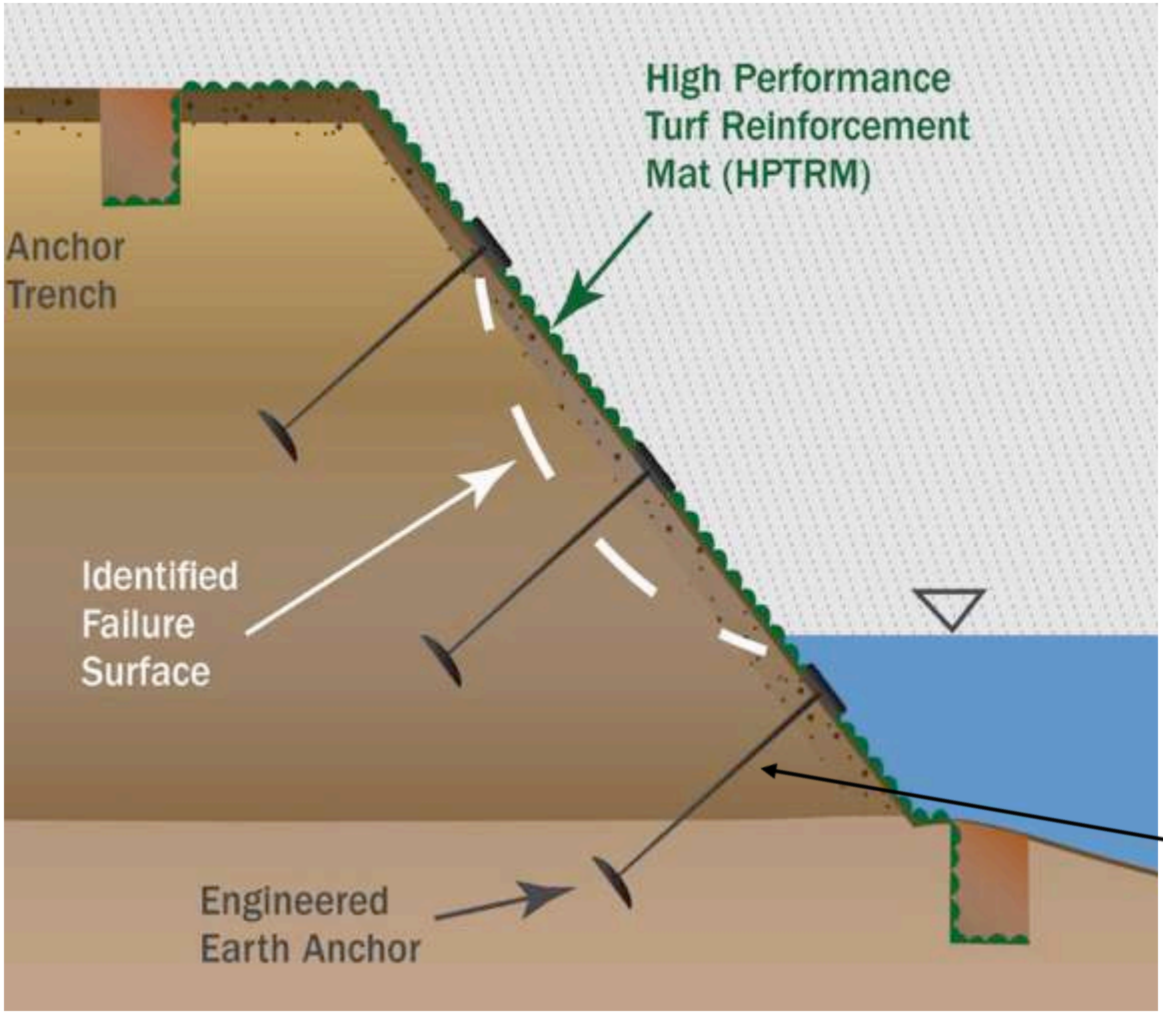
Randy Thompson, P.E.

Propex Geosolutions

Agenda

- Products and Solutions
- Slope Stability Design
- Case Study
- Questions and Discussion

Surficial Slope Stabilization with the ARMORMAX System



- Engineered Earth Anchors are designed to provide resistance to shear and lateral forces, and embedded beyond the predicted plane of failure
- HPTRM distributes loads amongst anchors while providing a continuous compressive cover
- HPTRM is also permeable for pore pressure relief and promotes vegetative establishment

Surficial Sloughing is often Incorrectly Treated as Erosion

These two photos are examples of a shallow plane slope failure that ARMORMAX could be used for the repair. Attempted repairs with erosion control blankets and low strength TRMs were unsuccessful.

Surficial Sloughing

- A shear failure in which a surficial portion of the embankment moves downslope is termed a surface slough.
- Surface sloughing is considered a maintenance problem, because it usually does not affect the structural capability of the embankment.
- However, repair of surficial failures can entail considerable cost.
- If such failures are not repaired, they can become progressively larger, and may then represent a threat to embankment safety.

USACE EM 1110-2-1902

ARMORMAX 75 for Slope Stabilization
Problem Areas for Consideration

A small landslip of the embankment threatening the stability of the track foundation. Along with correcting drainage issues, ARMORMAX 75 is evaluated through a geotechnical design to correct this type of failure.

Picture is taken from Network Rail, Earthworks Technical Strategy, June 2018.

ARMORMAX 75 for Slope Stabilization Problem Areas for Consideration

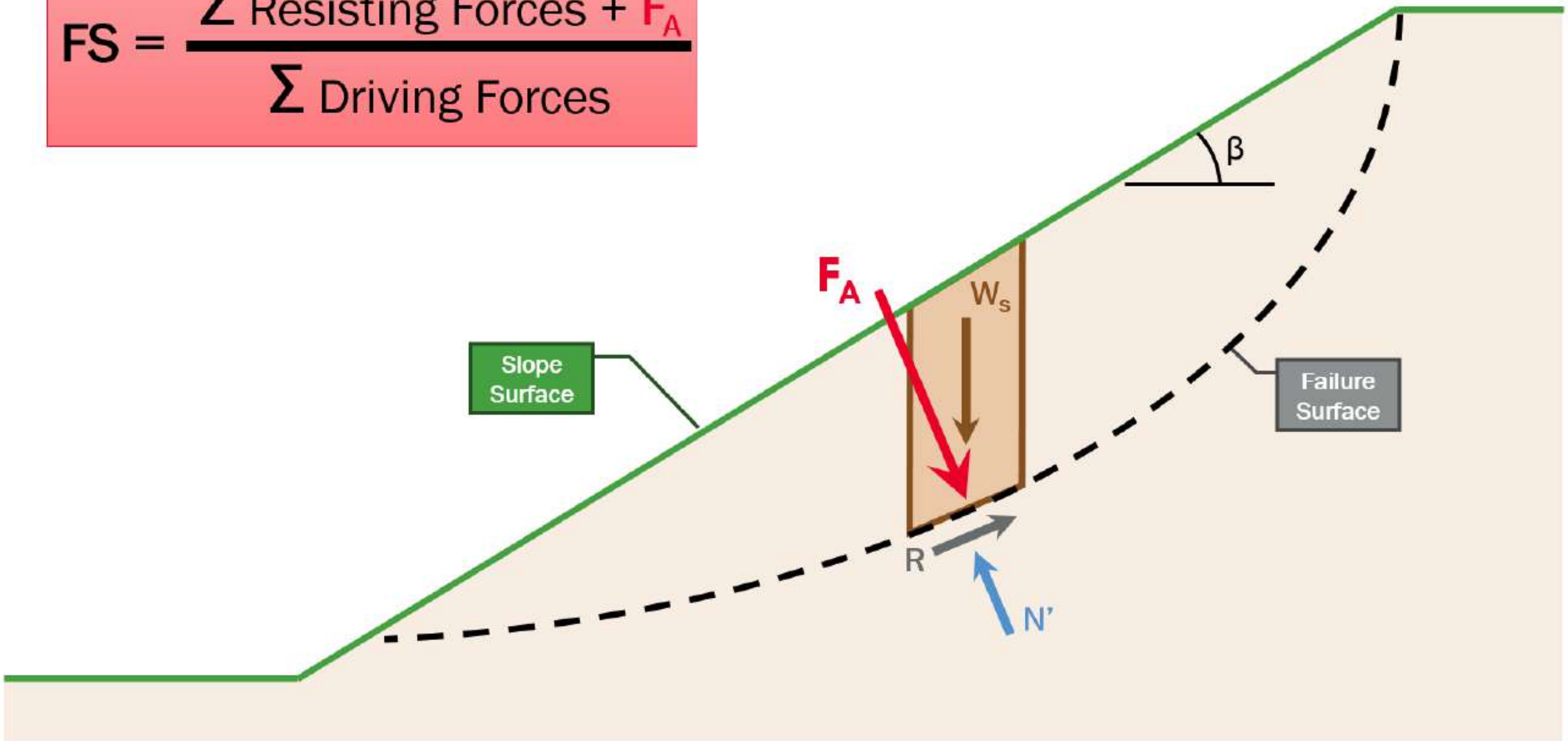
Above: Rapid failure of a soil cutting at Murthat in Scotland on the West Coast Main Line (Nov 2015). Asset showed no evidence of failure prior to slumping towards the track after a period of relatively normal rainfall. Failure identified by the driver of a passenger train travelling at 125mph.

The slumped slope above is typical of the type failure that ARMORMAX can be engineered to stabilize. Using soil nails to repair this shallow plane slope failure is overkill, expensive, and slow. Perhaps, a more traditional repair is to use the added weight of rip rap to stop the slope from slumping.

Picture is taken from Network Rail, Earthworks Technical Strategy, June 2018.

Surficial Stability Equation

$$FS = \frac{\sum \text{Resisting Forces} + F_A}{\sum \text{Driving Forces}}$$



Resting Forces > Driving Forces (Factor of Safety greater than 1.0) = slope stability
Resting Forces < Driving Forces (Factor of Safety less than 1.0) = slope instability

ARMORMAX System for Slope Stabilization

- GeoStudio's 2016 Slope/W Software
  - Slope stability determined through vertical slice limit equilibrium methods for given project conditions
  - Software determines, anchor size, drive depth, and frequency of installation
  - Minimum acceptable factor of safety (FS) for a slope under normal long-term loading conditions is 1.5
  - Under rapid drawdown conditions, FS =1.1

Anchor Driving with a Percussion Hammer

ARMORMAX Design Case History: Madalena Rail Station, Vila Nova de Gaia, Portugal

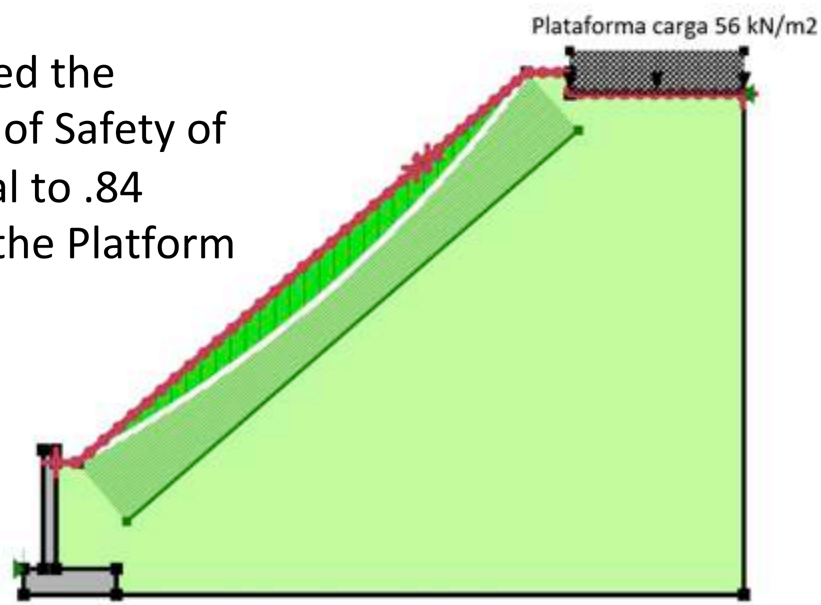
The picture on the left shows an aerial view of the Madalena Station and the picture on the right shows the slope to be redesigned to accommodate a wider and safer loading platform.

ARMORMAX Design Case History: Madalena Rail Station, Vila Nova de Gaia, Portugal

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Imported Fill	Mohr-Coulomb	18.06	0	35
	Retaining Wall	High Strength	23.56		

Factor of Safety Unreinforced =.84

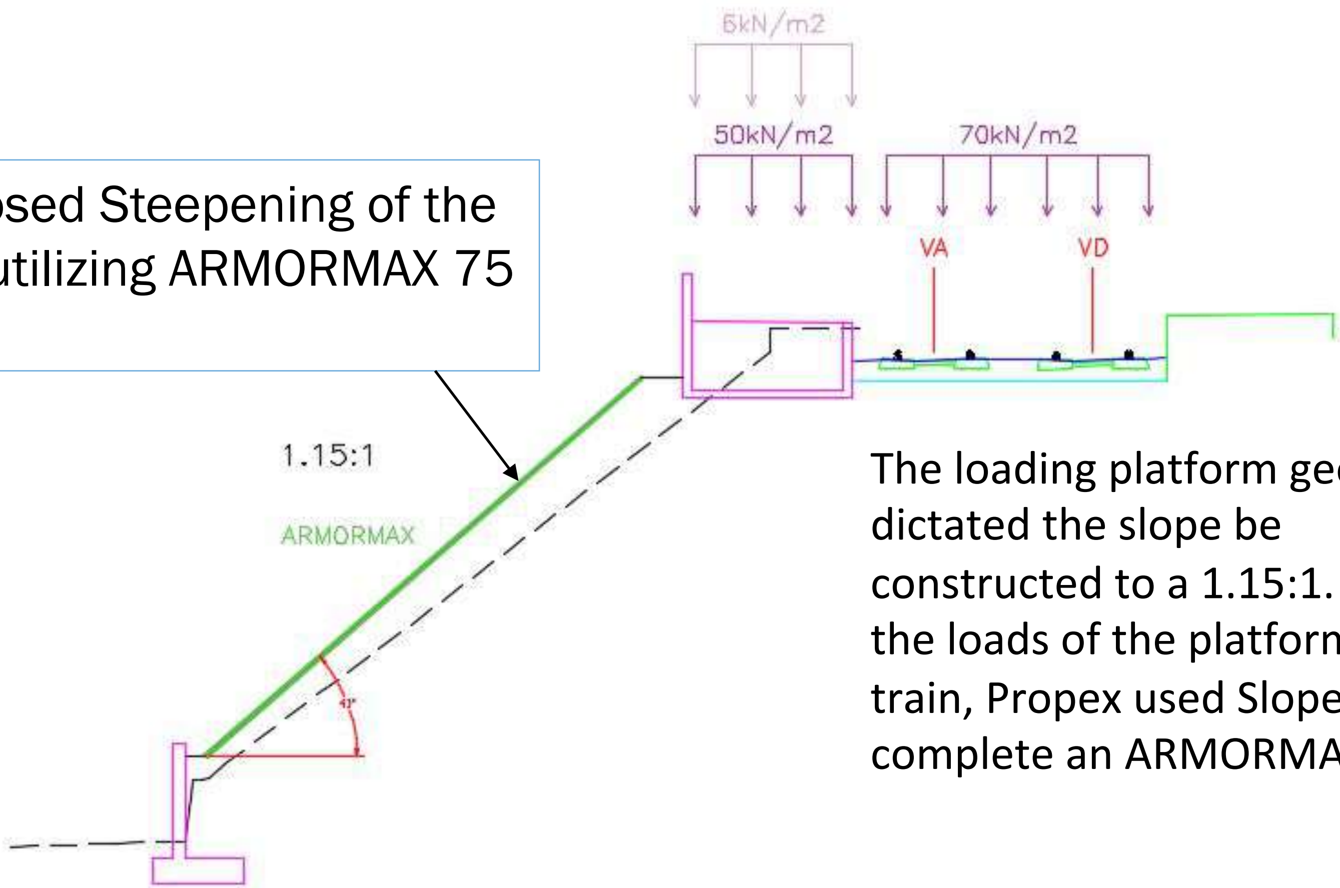
Propex first calculated the unreinforced Factor of Safety of the Slope to be equal to .84 taking into account the Platform Loading: 56 kN/m^2



1.15H:1V Unreinforced Slope; F.S.= 0.84

ARMORMAX Design Case History: Madalena Rail Station, Vila Nova de Gaia, Portugal

Proposed Steepening of the Slope utilizing ARMORMAX 75

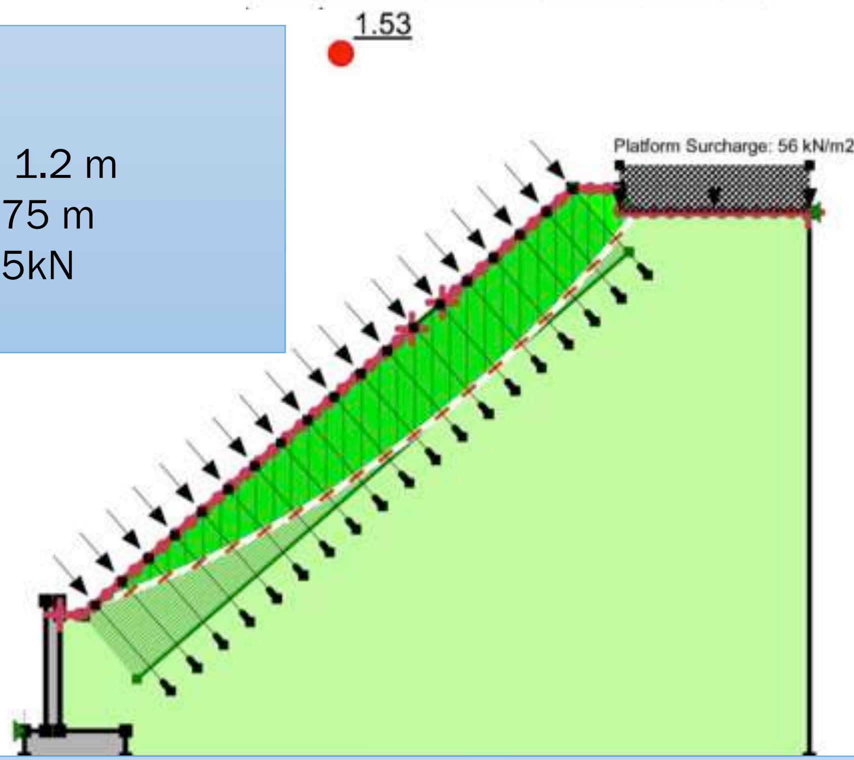


The loading platform geometry dictated the slope be constructed to a 1.15:1. Given the loads of the platform and train, Propex used Slope/W to complete an ARMORMAX Design

ARMORMAX Design Case History: Madalena Rail Station, Vila Nova de Gaia, Portugal Construction in 2019

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
(light green)	Imported Fill	Mohr-Coulomb	18.06	0	35
(grey)	Retaining Wall	High Strength	23.56		

Anchor Details:
Length=2.75 m
Horizontal Spacing = 1.2 m
Vertical Spacing = 0.75 m
Pullout Capacity = 8.5kN



1.15H:1V Slope Reinforced with ARMORMAX 75; F.S.= 1.53

ARMORMAX Installation Details

Re-grade the failed slope with the "sloughed" material

Shape the slope by removing objects that would prevent the ARMORMAX making intimate contact with the soil

ARMORMAX Installation Details

Unroll the High Performance Turf Reinforcement Mat on the prepared slope

Atlanta International Airport, USA

USACE Hurricane Protection Levee, New Orleans, Louisiana, USA

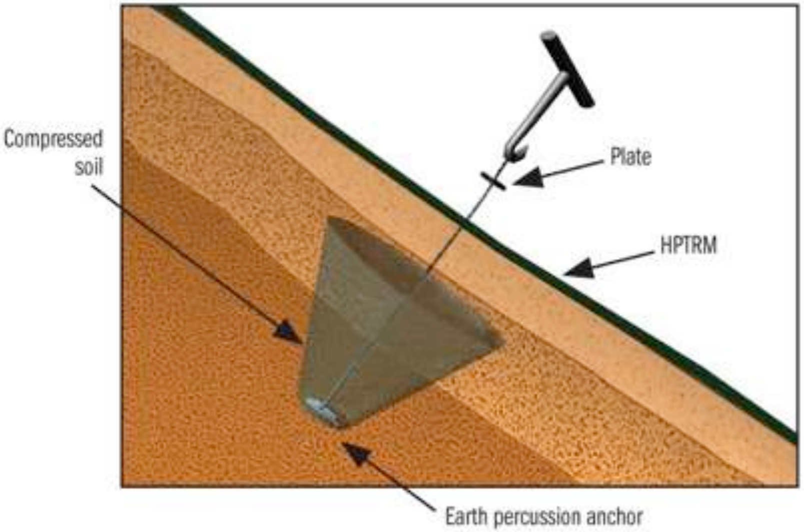
ARMORMAX Installation Details

Driving anchor with a breaker hammer mounted to an excavator

Manually driving anchor 2.5m (8') deep with 16kg (35#) air hammer on a steep slope

ARMORMAX Installation Details

- **Anchor is Load Locked to develop a Frustum Cone using a JackJaw.**
- **When a load is applied, the anchor will rotate in the ground by up to 90° and load lock.**
- **As the load exerted on the soil increases, a body of soil above the anchor is compressed and minimizes any further anchor movement. The size of the developed cone depends on:**
  - **The shear angle of the soil**
  - **The size of the anchor**
  - **The depth of installation**
  - **The load applied**



JackJaw Anchor Setting Tool

ARMORMAX Installation Details

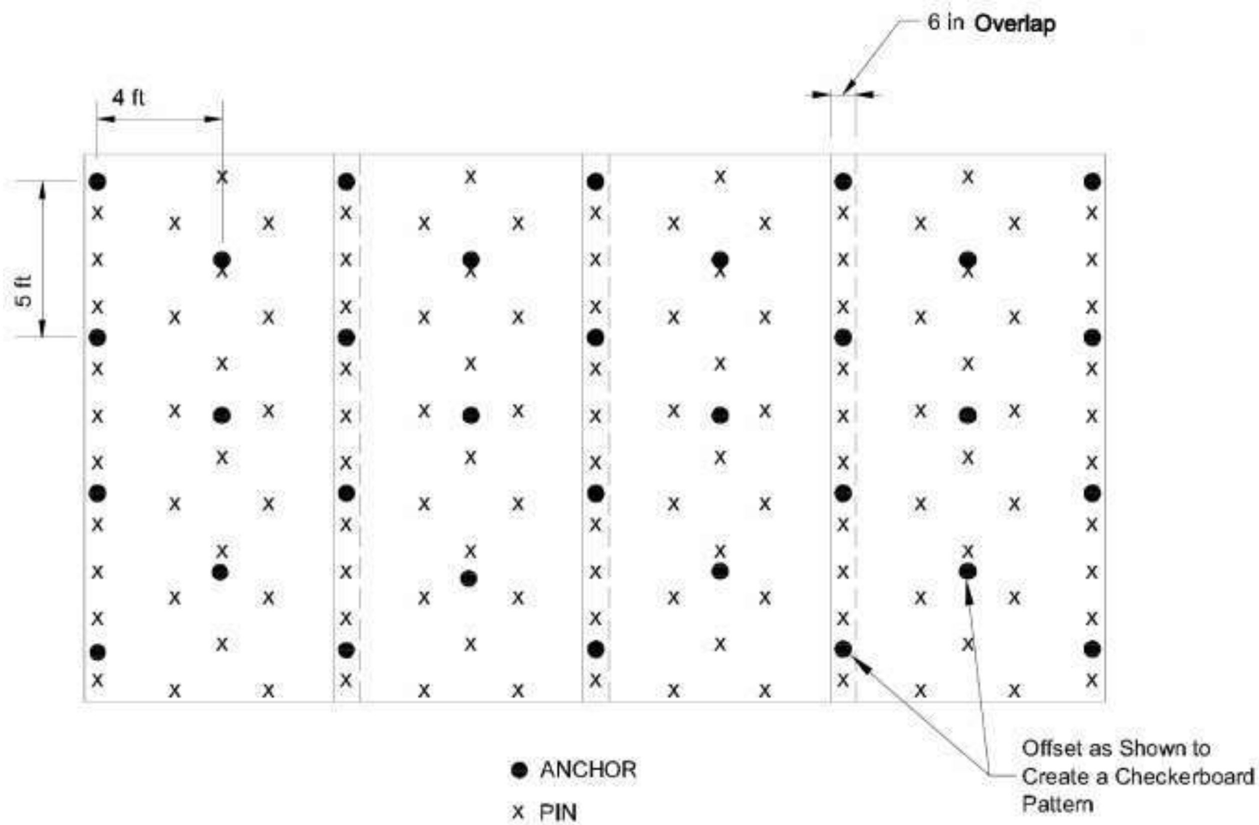


FIGURE 4:TYPE B2 ANCHOR / PIN PATTERN DETAIL FOR SLOPE FACE

Specified Anchoring Pattern

- Spacing of 1.2m (4') in the 'X' direction, 1.5m (5') in the "Y" direction
- 150mm (6")overlap for HPTRM panels
- Pattern staggered to secure HPTRM efficiently
- Spacing and density modeled in slope stability software

Finishing the ARMORMAX Installation

Top left: Hydro seeding on top of soil fill; **Bottom left**: placing turf; **Right:** Blown Fiber Matrix (BFM) and slope seed mixture

ARMORMAX and Soil Nail Combination in Alluvial Soils Case History: Metal Art Museum

- **Application:** Vegetated Slope Stabilization
- **Client:** City of Memphis, TN
- **Installed:** 2009
- **Product:** ARMORMAX®
  - 1.8m (6') Type B2 Anchors
  - 0.5 anchors per square yard
  - 0.6 anchors per square meter
- **Quantity:** 3,000 SY (2,500 SM)
- **Scenario:** Slope rehabilitation for museum hillside

  Replacement of failing gabion basket slope reinforcement

  Vegetated solution desired adjacent to Mississippi River

ARMORMAX and Soil Nail Combination in Alluvial Soils
Case History: Metal Art Museum

Original Design: 20m long soil nails on a 1.5m x1.5m pattern

Value Engineering Proposal utilized ARMORMAX to increased soil nail spacing to 2.4m x 2.4m

Close proximity to existing building, combination of rigid tendon anchors and deep soil nails

ARMORMAX and Soil Nail Combination in Alluvial Soils
Case History: Metal Art Museum


Anchor load testing and driving with percussion hammer

ARMORMAX and Soil Nail Combination in Alluvial Soils
Case History: Metal Art Museum

Small equipment used facilitating construction in limited easements

ARMORMAX and Soil Nail Combination in Alluvial Soils
Case History: Metal Art Museum

Hydro-seeding atop HPTRM with Blown Fiber Matrix (BFM) and slope seed mixture

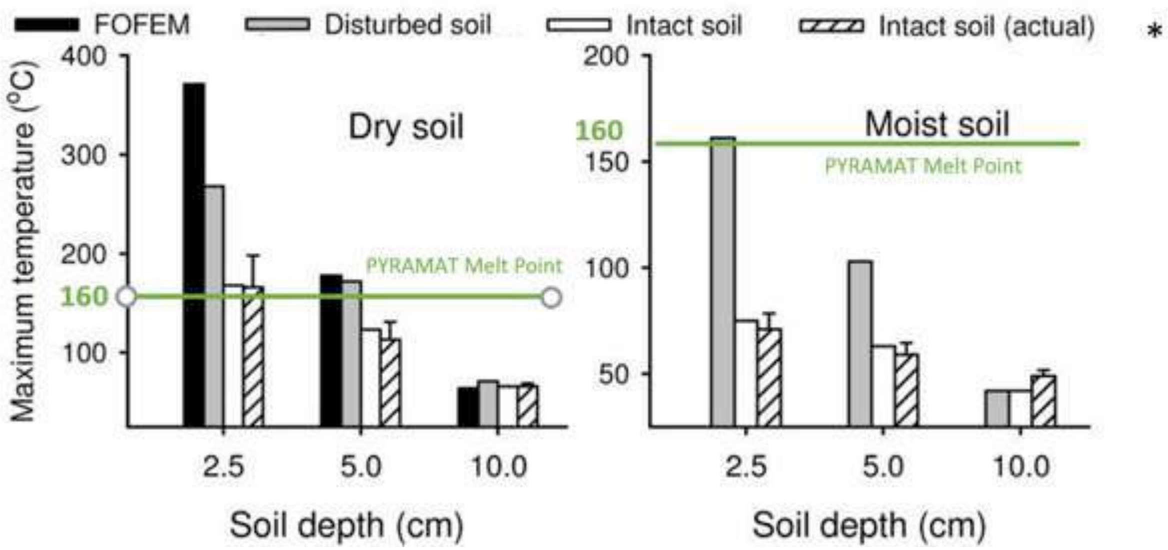
ARMORMAX and Soil Nail Combination in Alluvial Soils
Case History: Metal Art Museum

Finished Installation

ARMORMAX: Other Considerations
Propex Project Experience Worldwide

A Portfolio of Performance Supporting the use of this Technology

ARMORMAX: Other Considerations Performance in Wildfire Prone Areas



- FOFEM – First Order Fire Effects Model for predicting tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire.
- Measured soil heat profiles during 60 experimental burns, identifying changes in maximum soil temperature and heat duration as a function of soil moisture and soil texture.
- Underlying soils having 20% volumetric moisture or greater is an effective means for limiting lethal heating in a variety of soils.
- PYRAMAT normally placed under 2.5 cm (1”) of soil cover. In wildfire prone areas, consider using 7.5 to 15 cm (3 to 6”) of soil cover.

*Soil Science Society of America Journal Abstract - FOREST, RANGE & WILDLAND SOILS, Soil Physical Properties Regulate Lethal Heating during Burning of Woody Residues

ARMORMAX Summary for Slope Stability Solutions

ARMORMAX Reinforced Vegetated Slope may Replace the Above Traditional Methods or be used in Combination with the Above Solutions to Improve Performance

- Proven through an engineering design
- Generally at least half the installed cost of traditional solutions
- Portfolio of performance on projects around the world
- Strong environmental argument to reduce carbon on construction projects
- Installs more quickly with small equipment minimizing work zone danger

Propex GEOSOLUTIONS **Propex is an International Company that has been in business for over 100 years**

*Picture is taken from Network Rail, Earthworks Technical Strategy, June 2018.

Conclusion
Project Discussion and Questions

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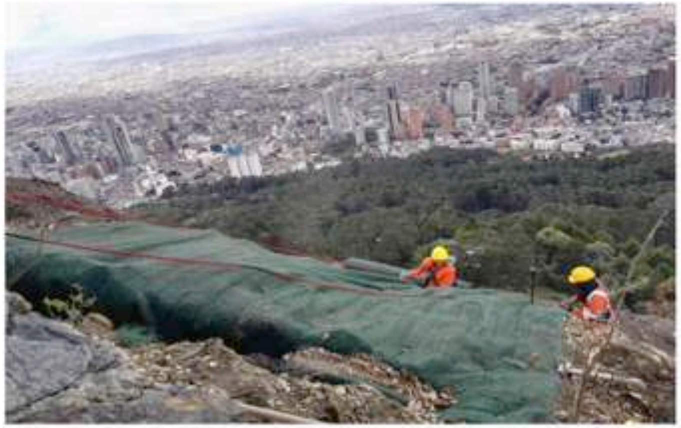

Slope Protection, Bogota, Columbia