Association of Geotechnical and Geoenvironmental Specialists (HK)
One-day Seminar on "Ground Improvement"
Hong Kong - May 12th, 2018

Jet Grouting

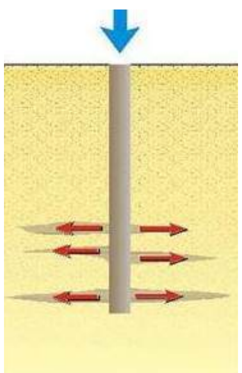
Eng. Bruno Vingiani
www.trevispa.com

TREVIGroup

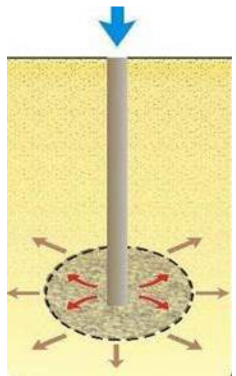
1. Basic principles
2. Main features
3. Required equipment and jobsite organization
4. Quality controls
5. Recent innovations by Trevi
6. Typical applications in Hong Kong (by Claudio Borgatti – GM of *Trevi Construction HK*)

Soft/loose soils improvement methods

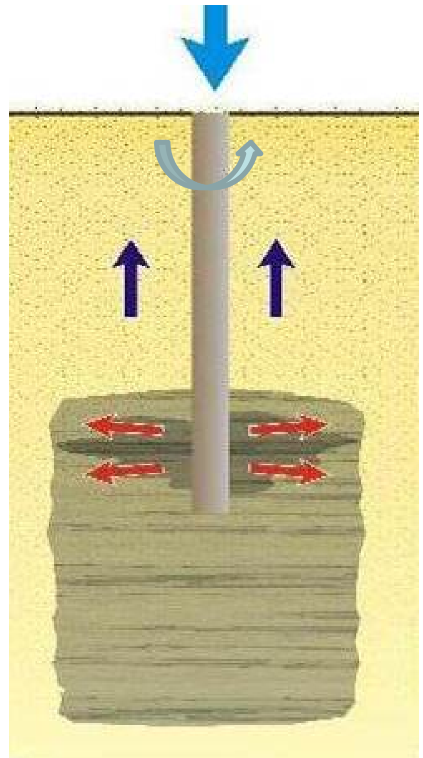
Several methods and relevant technologies are nowadays available for improving hydraulic and mechanical characteristics of soft and loose soils by means of a binding agent (in a dry or fluid form). Jet Grouting belongs to this “family” of methods.



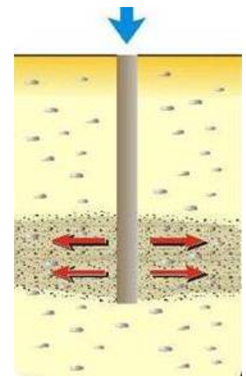
hydraulic fracturing



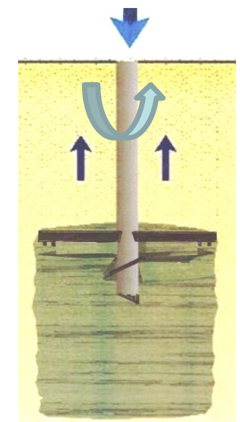
compaction grouting



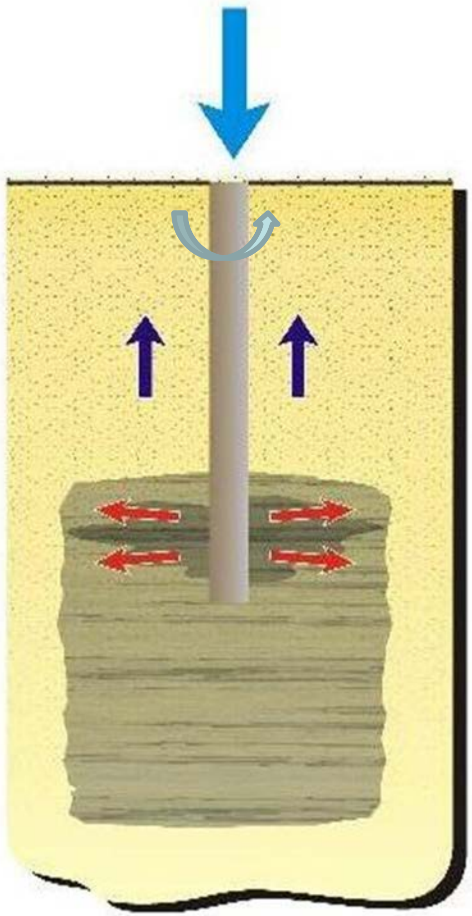
jet grouting



permeation grouting



deep soil mixing



Jet Grouting is an improvement method that involves the erosion of the in-situ soil structure by means of high energy jets of one or more fluids and its mixing in place with a cement grout mix.

For all members of the European Committee for Standardization (ECS), the applicable standard for the execution, testing and monitoring of JET GROUTING WORKS is:

EN 12716:2001

“*Execution of special geotechnical works – Jet Grouting*”

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1965/70	conception and first experiments (Yamakado, Japan);
1970	development of the “*single-fluid*” system ("*Chemical Churning Pile*" or CCP, Nakanishi, Japan);
1972	development of the “*double-fluid*” system ("*Jumbo Jet Special Grout"* or JSG, CCP, Japan);
1975	development of the “*triple-fluid*” system ("*Column Jet Grout*" or CJG, Kajima Corporation, Japan);
1980/...	successful introduction in Europe and worldwide diffusion mainly through Italian and German specialized contractors

Typical operational phases

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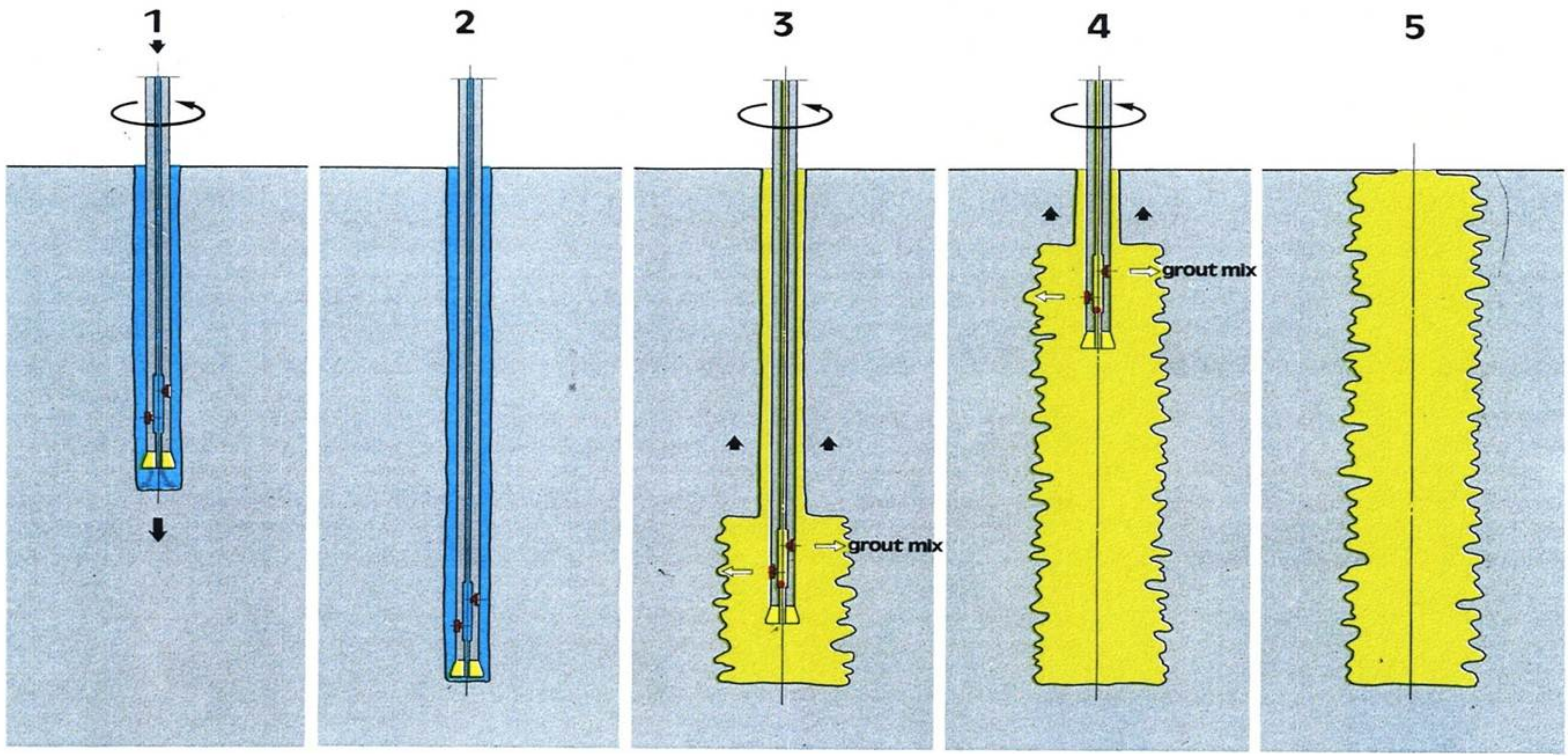
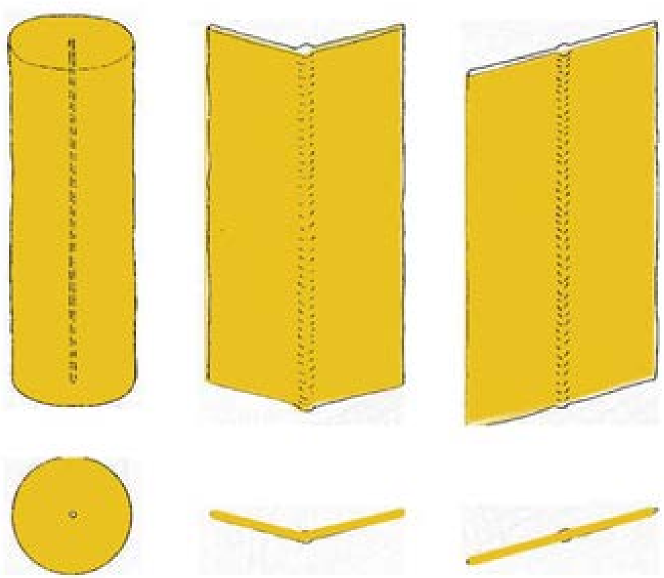
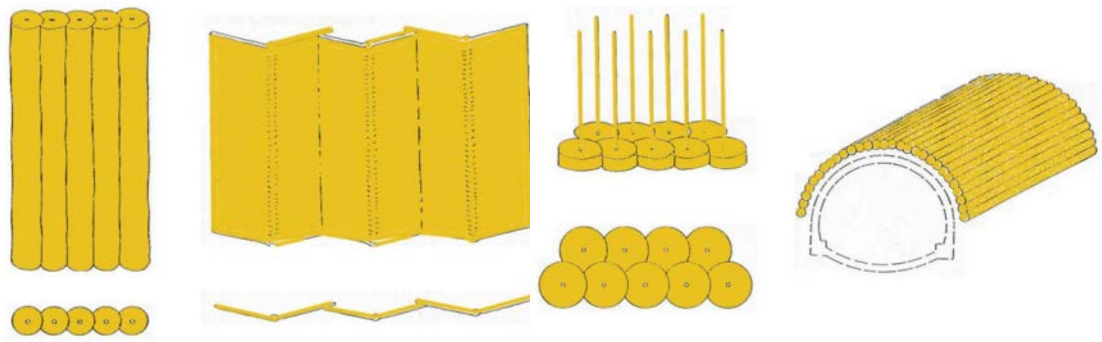


Rotary, roto-percussion or DTHH drilling	Achieving the design depth	High pressure injection while turning and extracting the rods in a controlled manner	Continue the process up to the design top elevation	Completed column of treated soil

Geometry of the treated soil

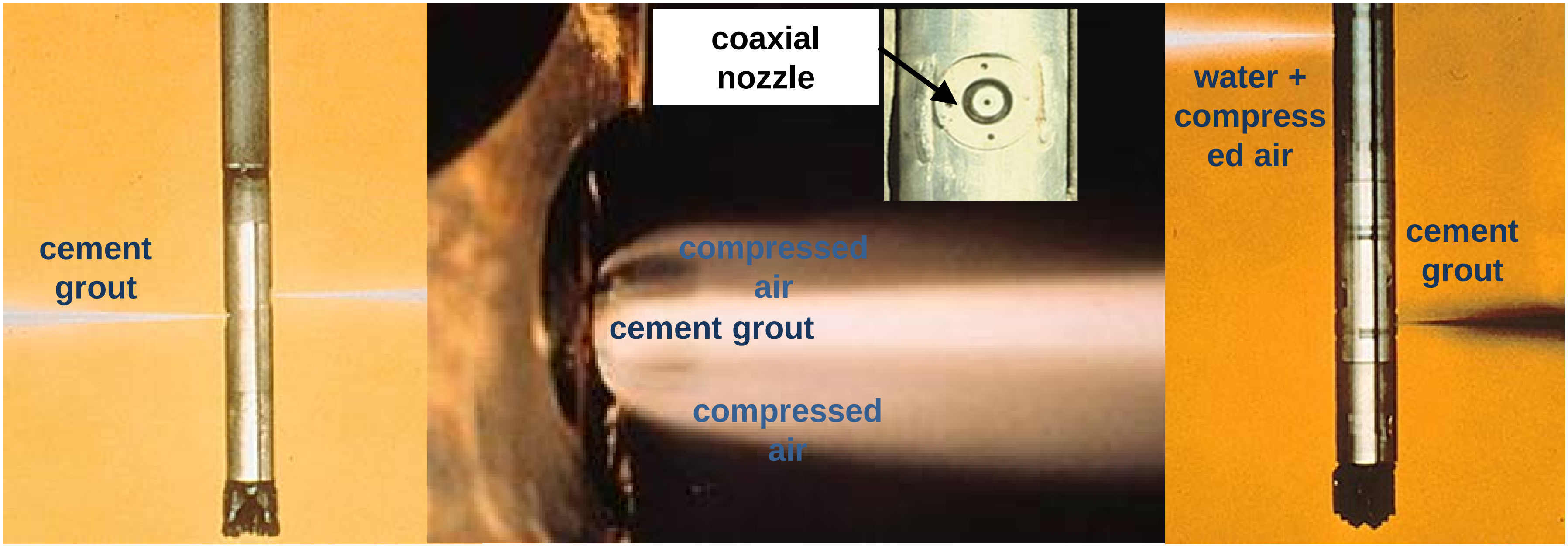


basic elements
(columns and thin panels)



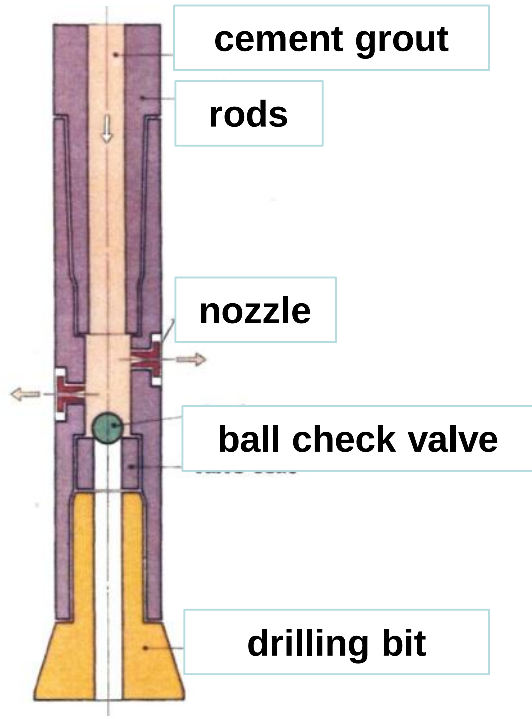
complex structures
(by combining basic elements)

The high-velocity jets are achieved by pumping the fluids at high pressure and forcing them to exit from small diameters (2÷6 mm) nozzles located at the bottom of the drilling rods.



“single-fluid”	“double-fluid”	“triple-fluid”
one single fluid (cement grout) for both, eroding and cementing the soil	two fluids (cement grout & compressed air) for both, eroding and cementing the soil	two fluids (water & compressed air) for eroding and one fluid (cement grout) for cementing the soil

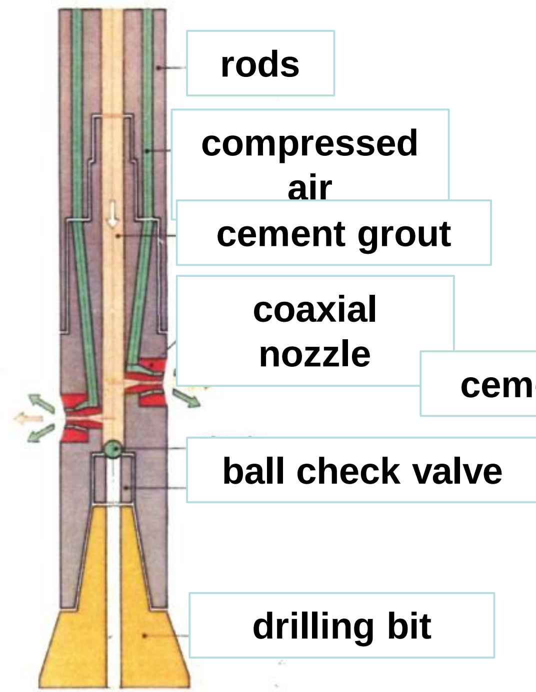
The effect of the compressed air is to increase the radius of action of the grout ("double-fluid") or water ("triple-fluid").



“single-fluid”

Typical column’s diameters:

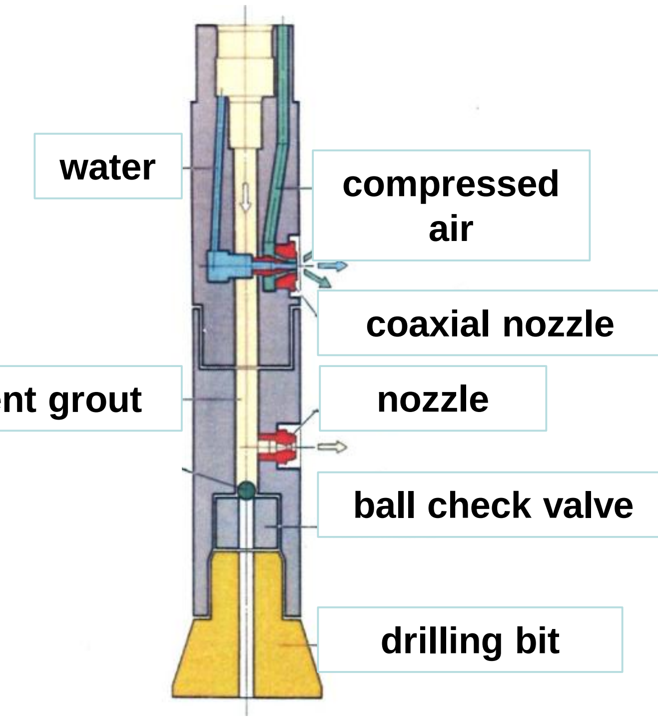
40 ÷ 120 cm



“double-fluid”

Typical column’s diameters:

80 ÷ 250 cm



“triple-fluid”

Typical column’s diameters:

200 ÷ 400 cm

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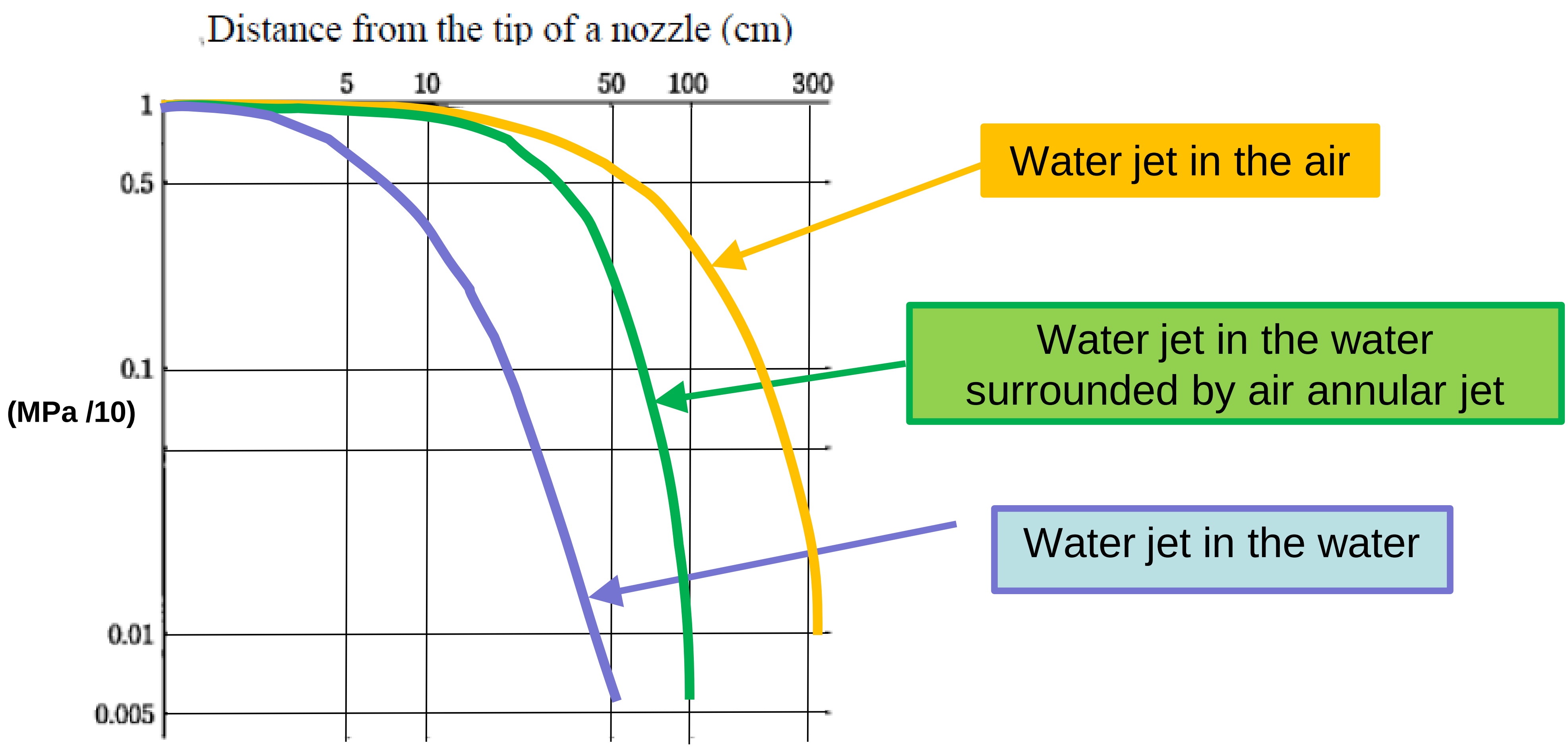
Distance from the tip of a nozzle (cm)
5
10
50
100
300
1
0.5
0.1
(MPa /10)
0.01
0.005
Water jet in the air
Water jet in the water surrounded by air annular jet
Water jet in the water

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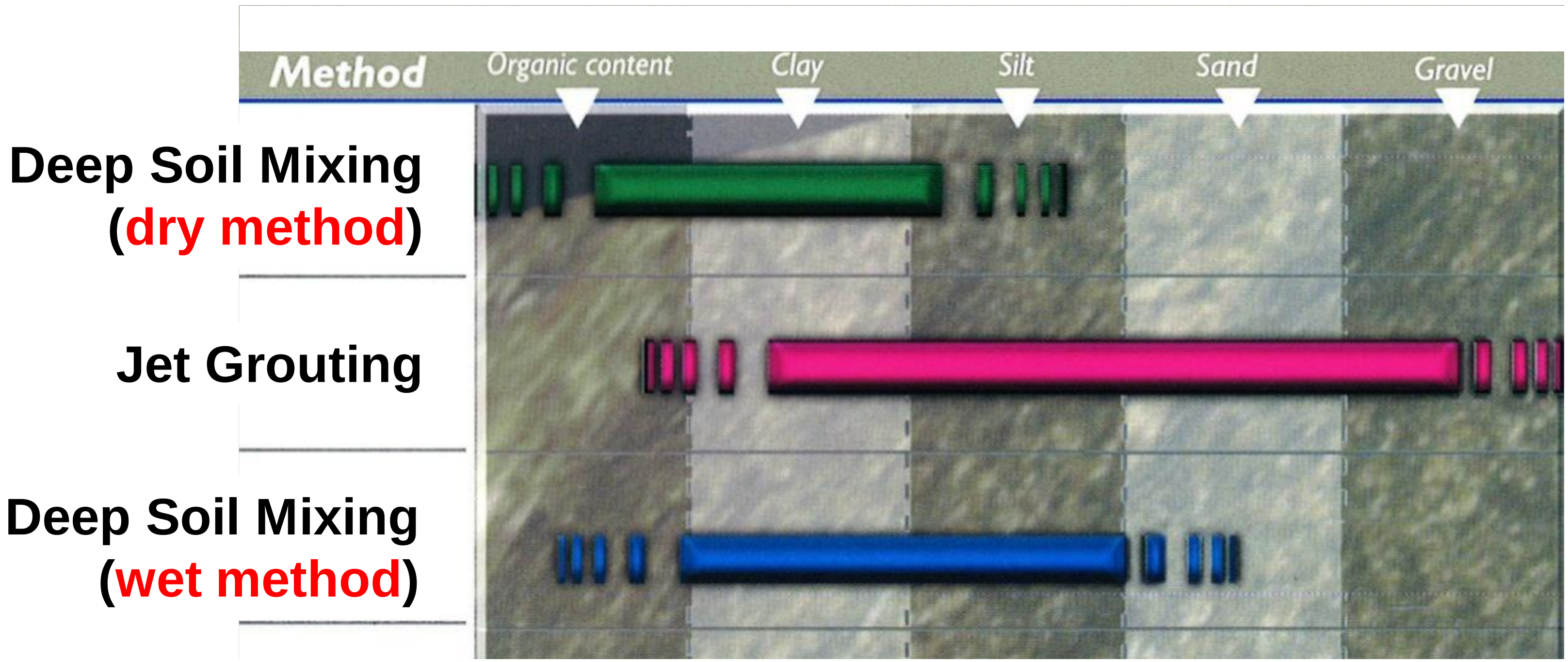
Parameter		"single fluid"	"double fluid"	"triple fluid"
Grout pressure	(MPa)	30÷50	30÷50	6÷20
Grout flow rate	(l/min.)	50÷450	50÷450	50÷200
Water pressure	(MPa)	-	-	30÷50
Water flow rate	(l/min.)	-	-	50÷200
Air pressure	(MPa)	-	0,2÷1,7	0,2÷1,7
Air flow rate	(m^3/min.)	-	3÷12	3÷12
Rods rotation speed	(r.p.m.)	6÷20	6÷20	6÷20

Final working parameters shall always be selected according to the results of one or more preliminary full-scale trial fields to be performed in the same area(s) of intervention.

Among all other soil improvement methods involving the use of a binding agent, Jet Grouting is the one applicable to the largest range of soils.

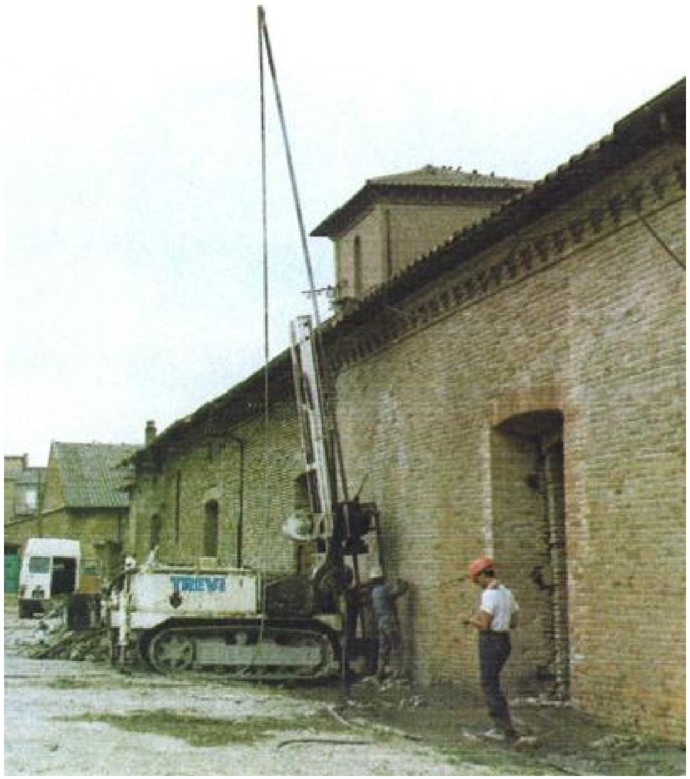


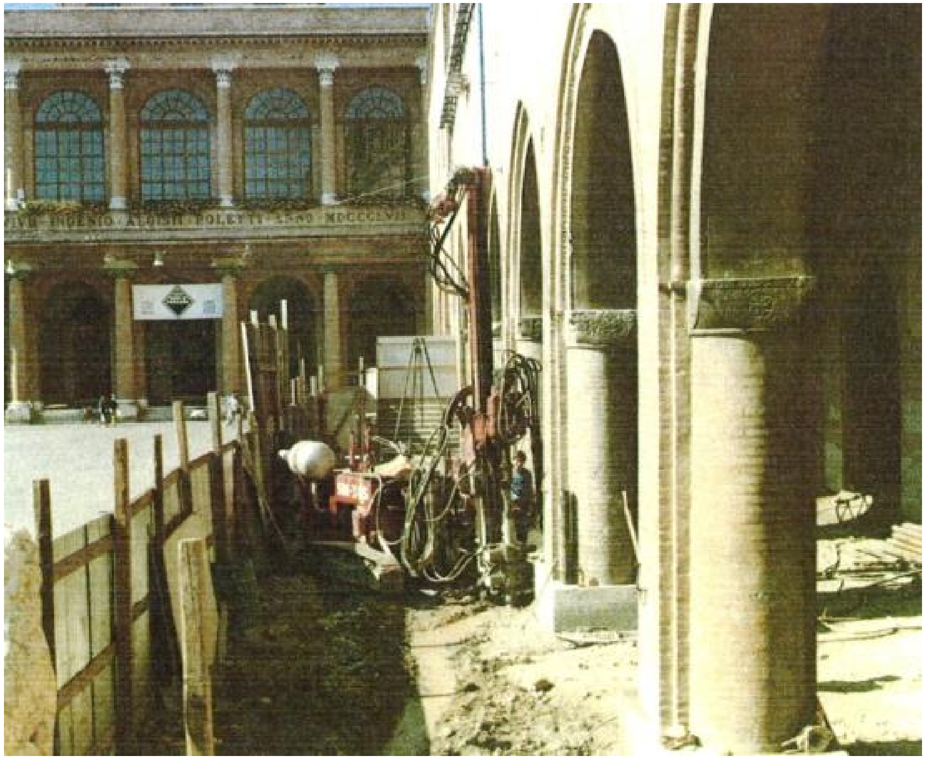
The achievable diameters depend on a large number of factors, the main of which is the erodibility of the concerned soil.

Loose coarse gravel

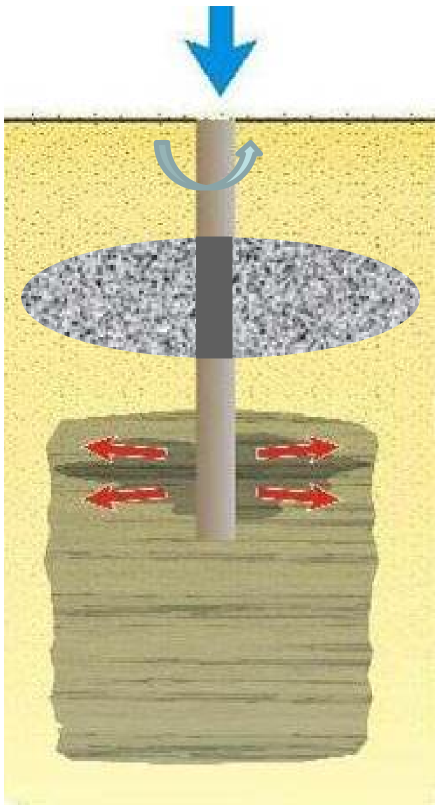
Plastic clay

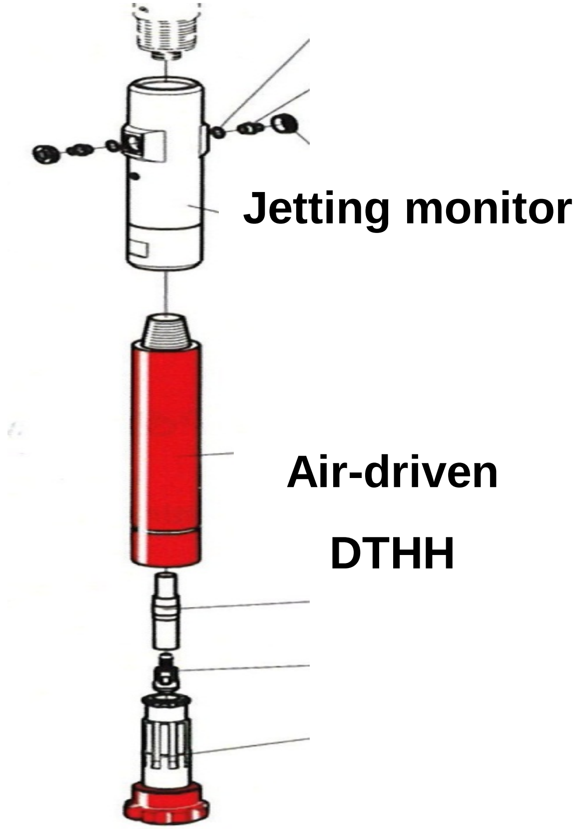
Starting from a small diameter drilled hole (100 ÷ 180 mm), it is possible to produce a consolidated soil column up to 4 m in diameter. As a result of this, also small drilling rigs can be employed for performing Jet Grouting and small working spaces do not hamper its employment.

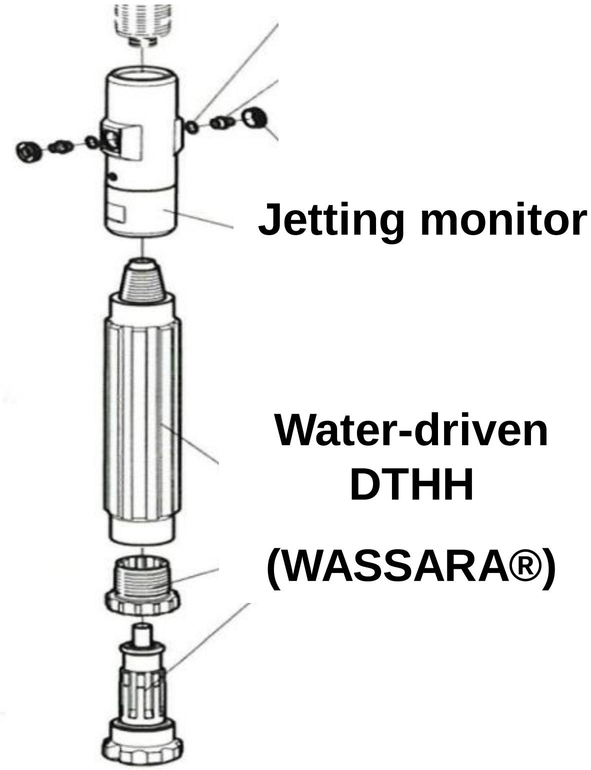




By using the most appropriate drilling technology, it is possible to pass through natural (i.e. boulders, rocky formations etc.) or man-made (i.e. old masonry or concrete foundations etc.) obstacles.







“single-fluid”

Hydraulic drilling rig with automatic grouting parameters recorder

Automatic high capacity (20-25 m^3/h) grout batching plant

High pressure (40-60 MPa) grout pump

“double-fluid"

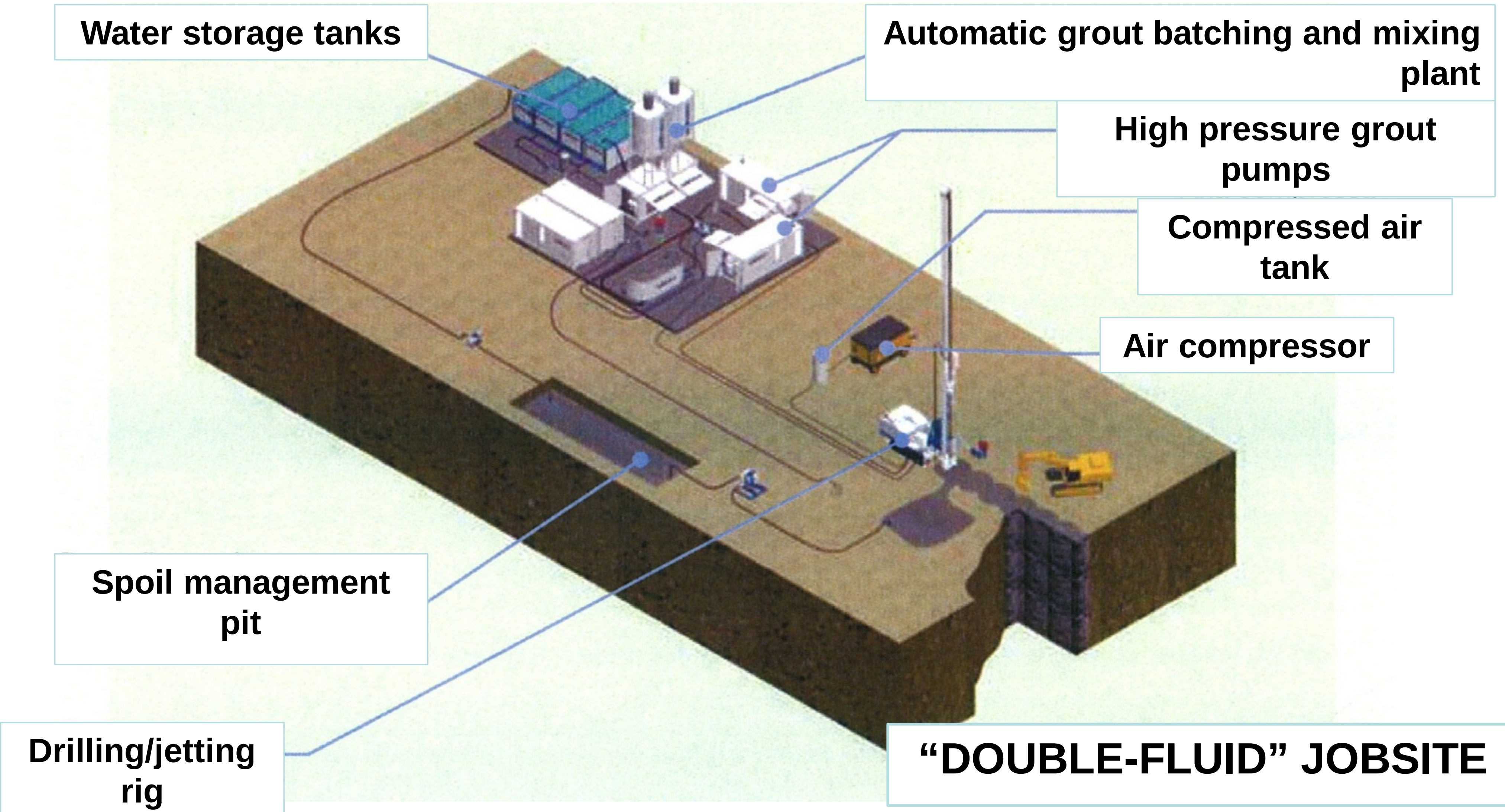
+

High capacity (20 m^3/min at 2 MPa) air compressor

“triple fluid"

+

Medium pressure (20-30 MPa) grout pump


Water storage tanks
Automatic grout batching and mixing plant
High pressure grout pumps
Compressed air tank
Air compressor
Spoil management pit
Drilling/jetting rig
"DOUBLE-FLUID" JOBSITE

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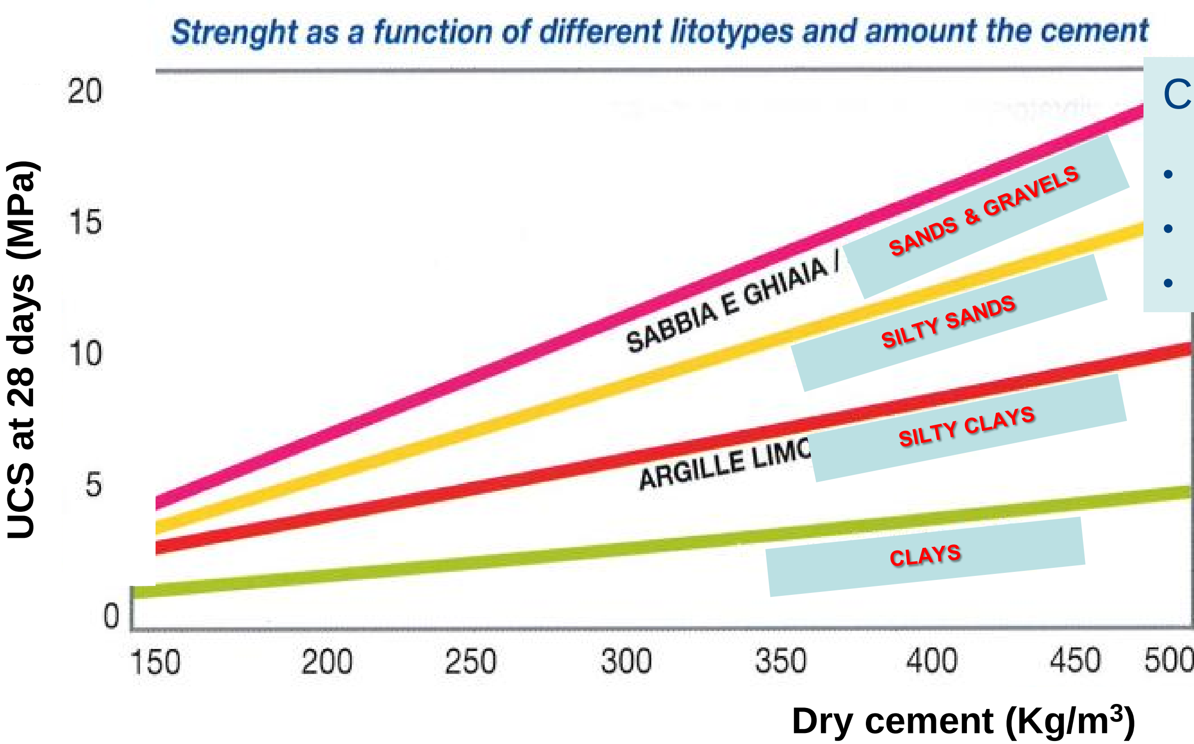
The final result of the Jet Grouting process is a mix of water, cement and original soil. Consequently, the final strength of the treated soil is directly correlated to two main factors: (1) the nature of the original soil and (2) the quantity of cement introduced into the process.



Cement content (typical quantities):

- single-fluid : 200÷400 kg/m³
- double.-fluid : 200÷800 kg/m³
- triple-fluid : 400÷1000 kg/m³

Concerning permeability, the values usually range between 10^{-4} cm/s and 10^{-5} cm/s, with lower values related to clayey soils.

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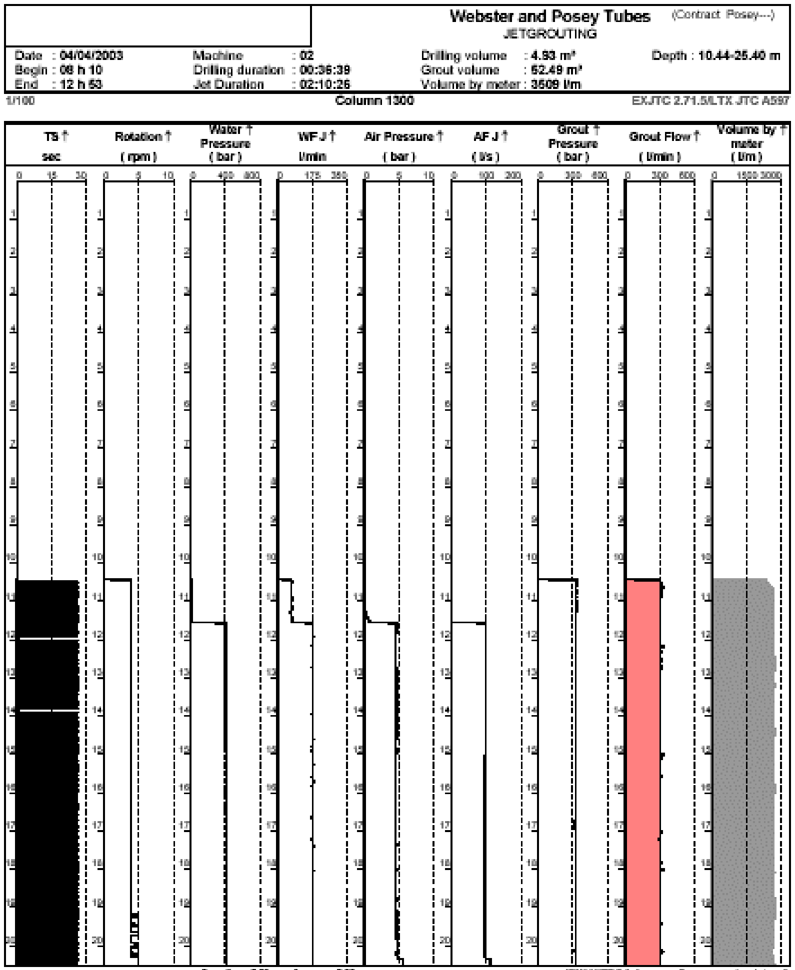
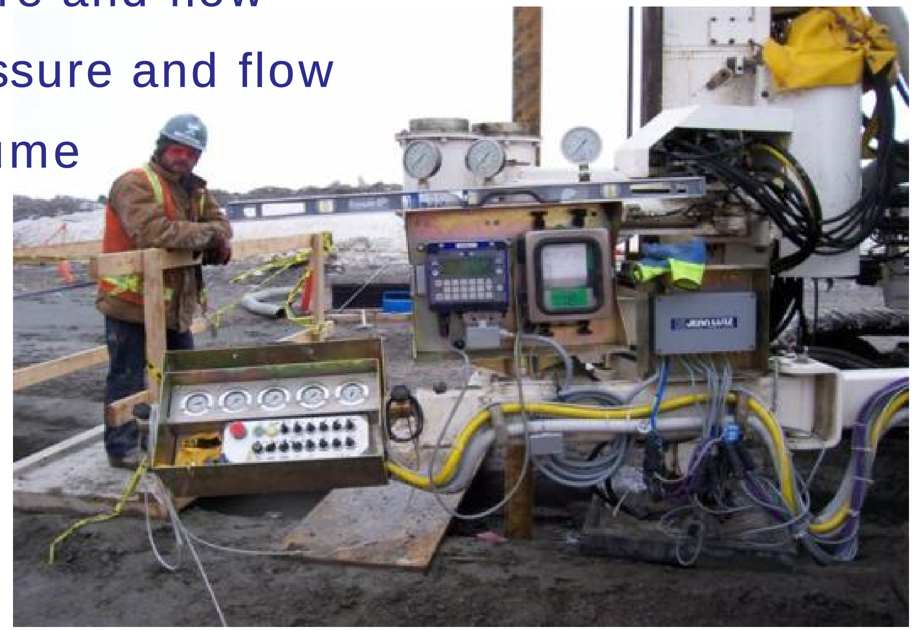
Before execution	During execution	After execution
➢ Comprehensive soil investigation and testing ➢ Full-scale trial field(s)	➢ Rheological characteristics of the grout ➢ Borehole starting position ➢ Drilling and jetting parameters ➢ Borehole deviation ➢ Free flow of the return spoil	➢ Cored holes ➢ In-situ testing inside the cored holes ➢ Laboratory testing on cored samples ➢ Pumping tests ➢ Other tests according to the final scope of the intervention



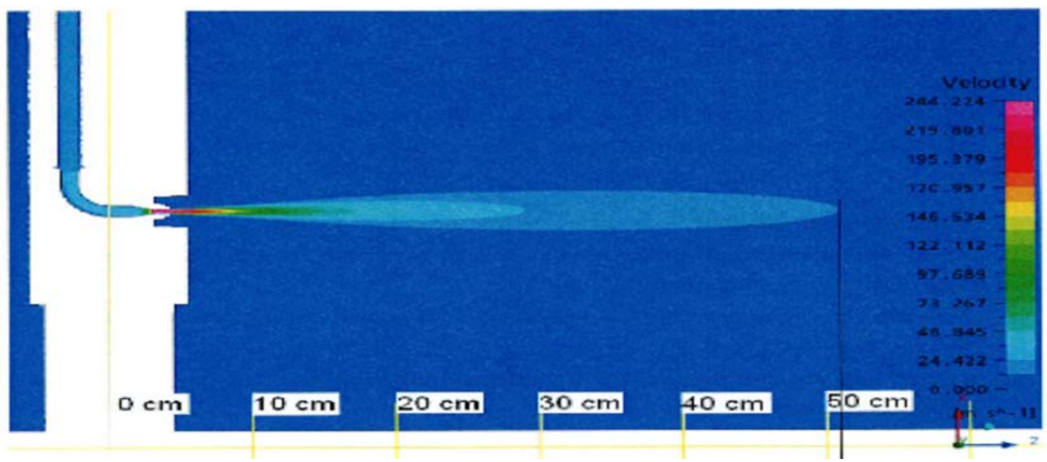
Jetting Parameters

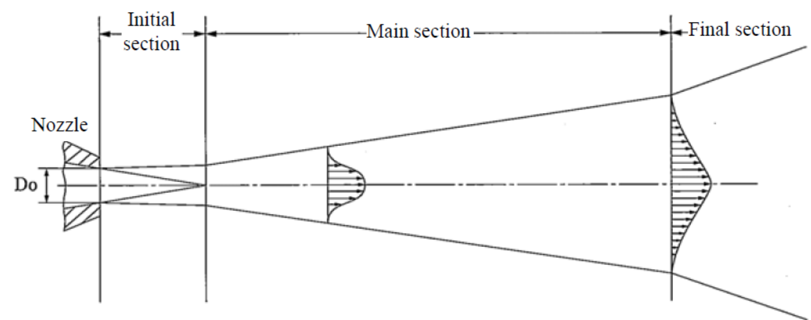
- Depth
- Withdrawal rate
- Rotation speed
- Water pressure and flow
- Air pressure and flow
- Grout pressure and flow
- Grout volume



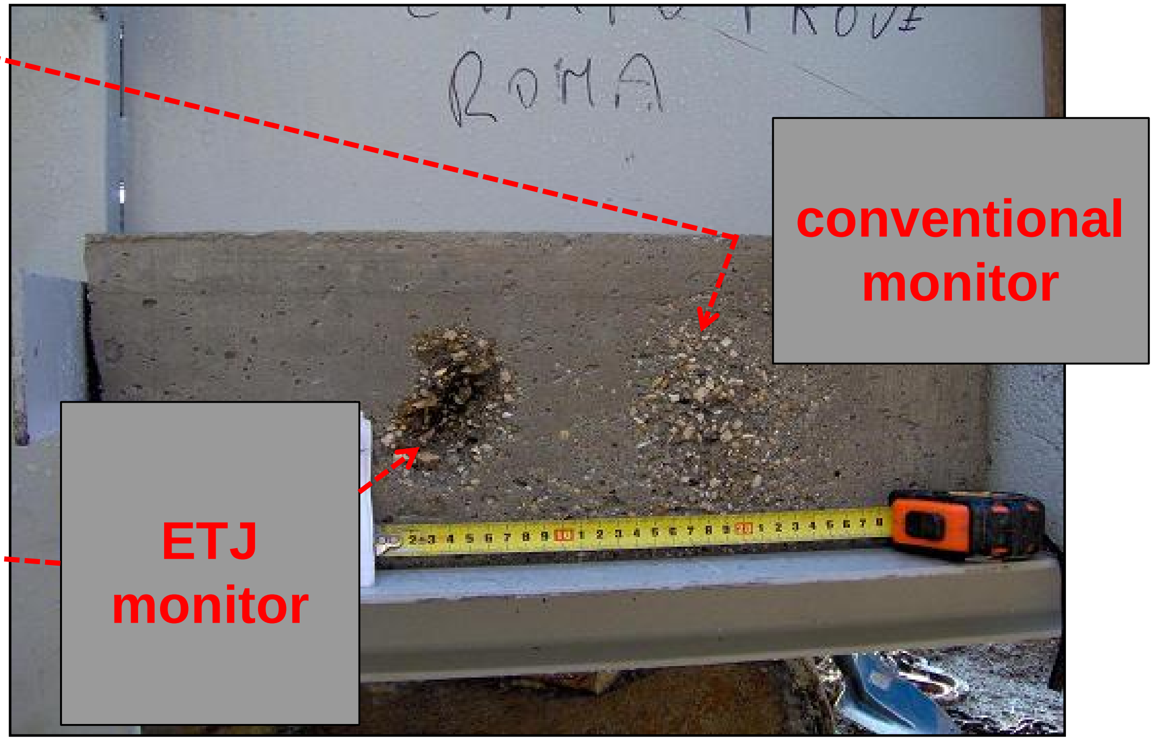
The capability to erode and break up the soil depends on the shape of the jet after its exit from the nozzle. The less the jet widens the greater is its efficiency, and the diameter of the column that can be achieved.

TREVI has carried out extensive theoretical and practical researches on this issue, which has led to the development of a newly-conceived jetting monitor, the Enhanced Trevi Jet (ETJ). In the ETJ, unlike traditional monitors, the grout or water flow is "accompanied" in its exit from the nozzle by means of a curved conduit. The result is a much more "close" jet at greater distance.

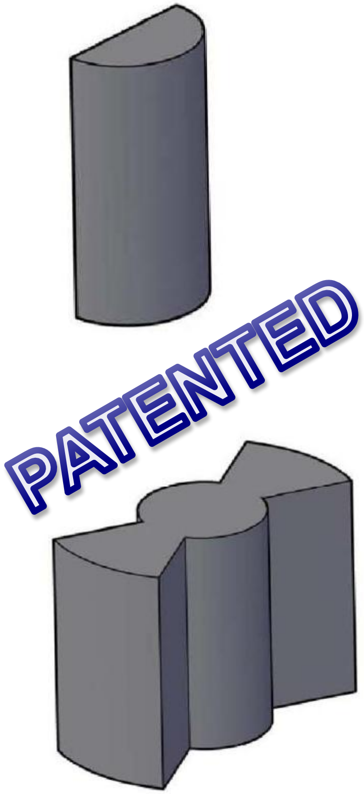




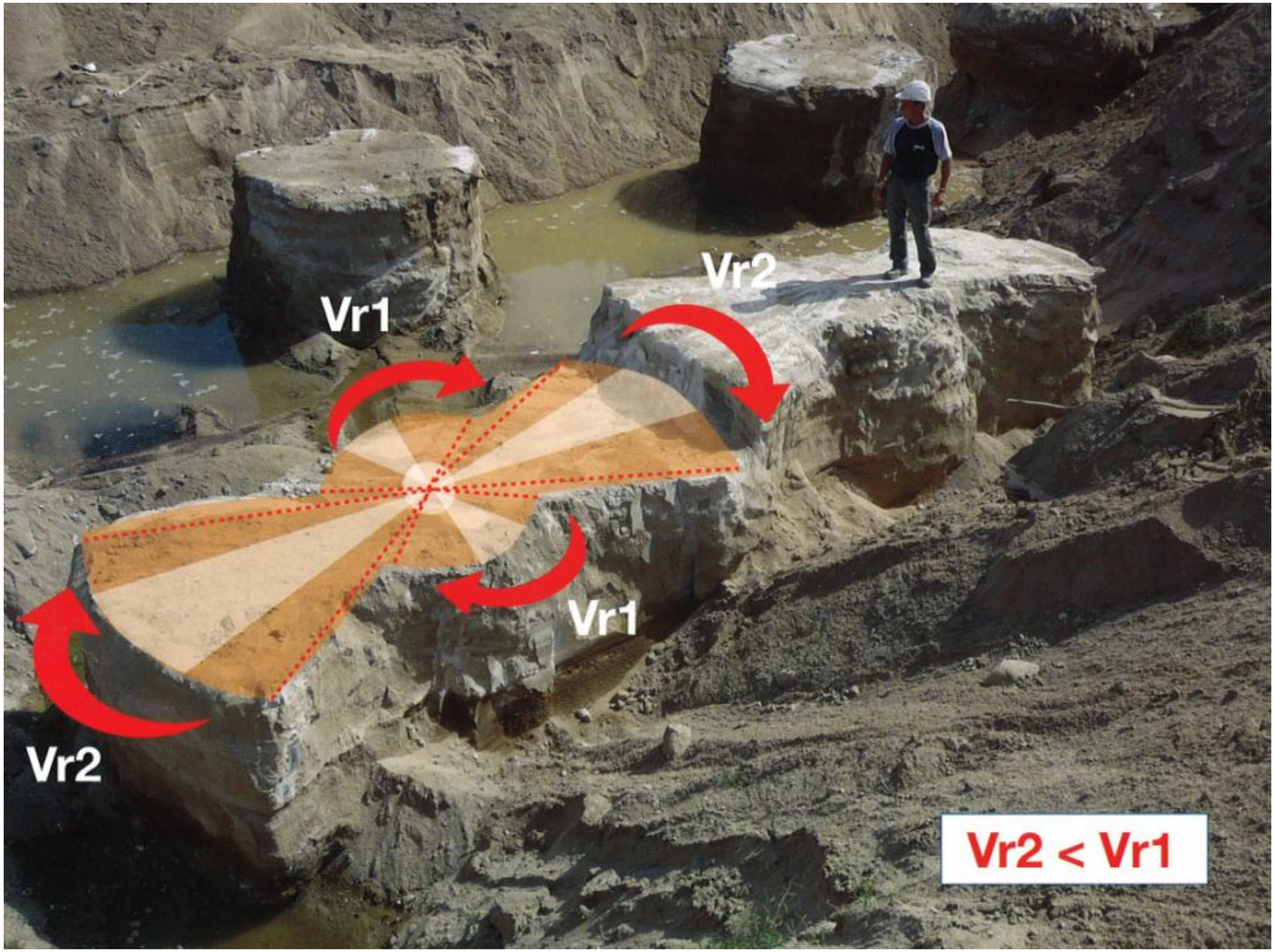
The ETJ monitor, already applied in dozens of jobsites, proved to be around 20% more efficient than any other conventional monitor, regardless of the nature of the treated soil.



There are some situations where the circular shape of the treated soil is not the most efficient. TREVI has developed and patented a system for performing also different configurations.

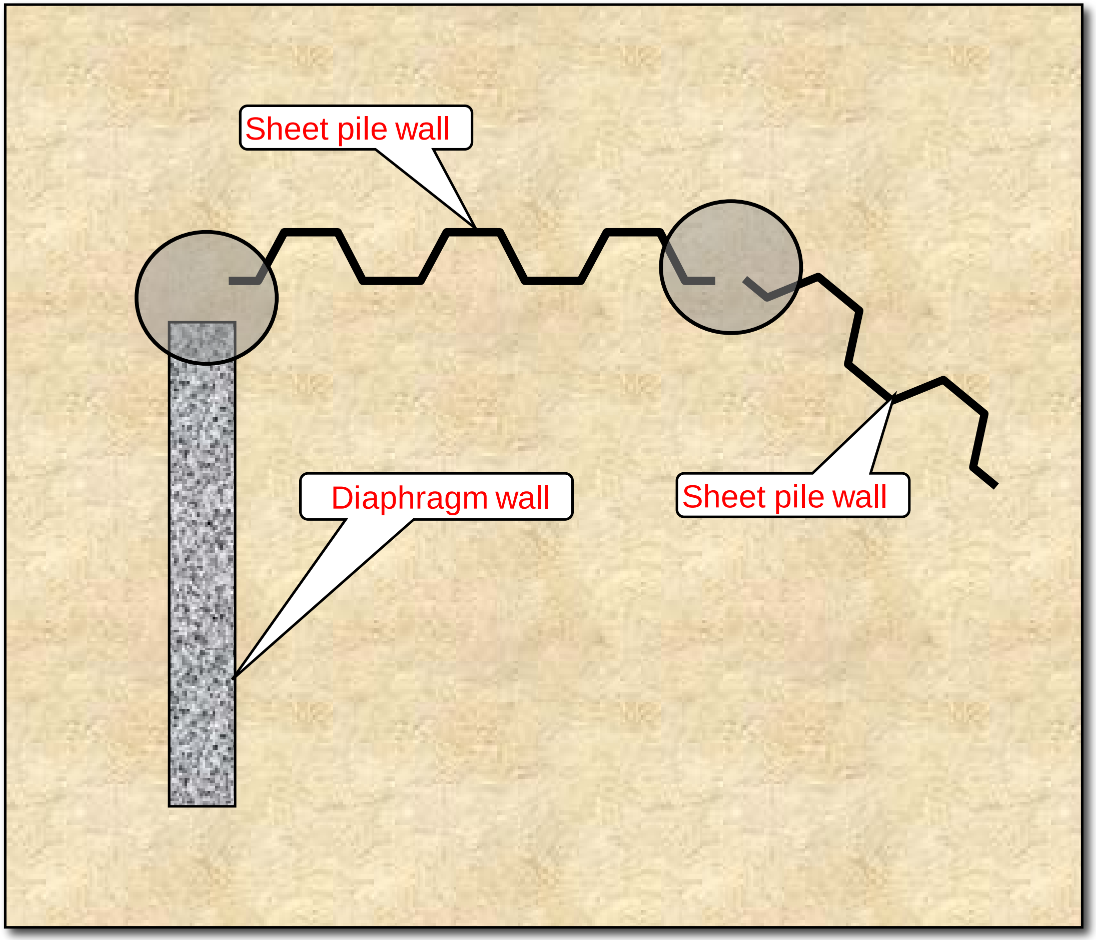


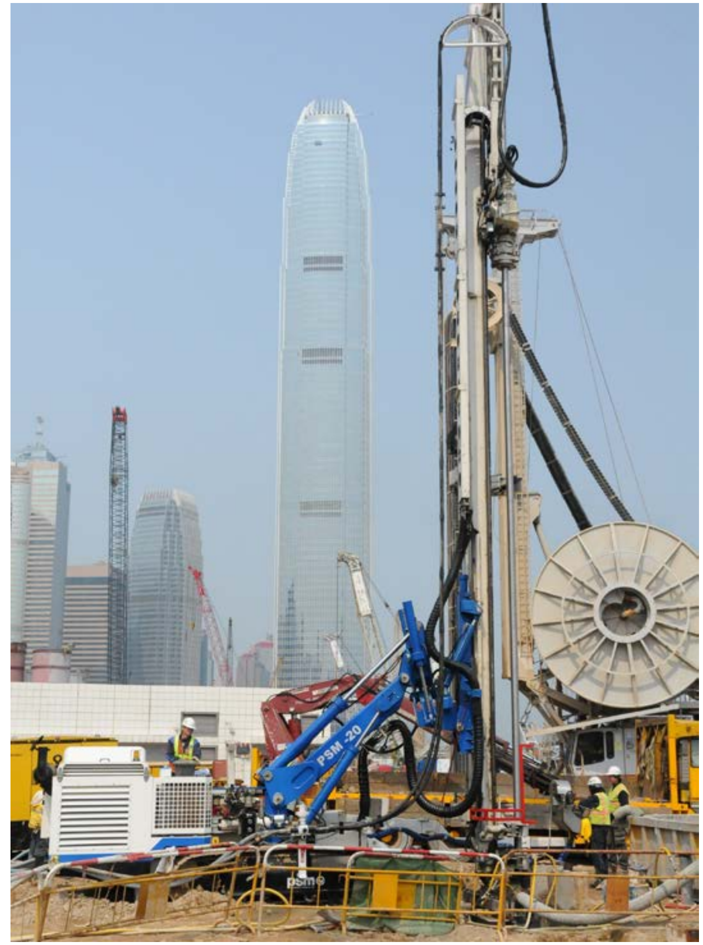
Vr2 < Vr1


Vr2
Vr1
Vr1
Vr2
Vr2 < Vr1

JET GROUTING APPLICATIONS IN HONG KONG

Closing gaps between adjacent structures (sealing column)





***Project*: Central Reclamation Phase 3**

***Consultant*: Atkins**

***Main Contractor*: LCSVO JV**

***Scope of Works*: Jet Grouting as cut-off curtain under existing 4-cell culvert for future excavation of Wan Chai by-pass**

***Progress* : Job started in October 2009 and was completed in May 2010**

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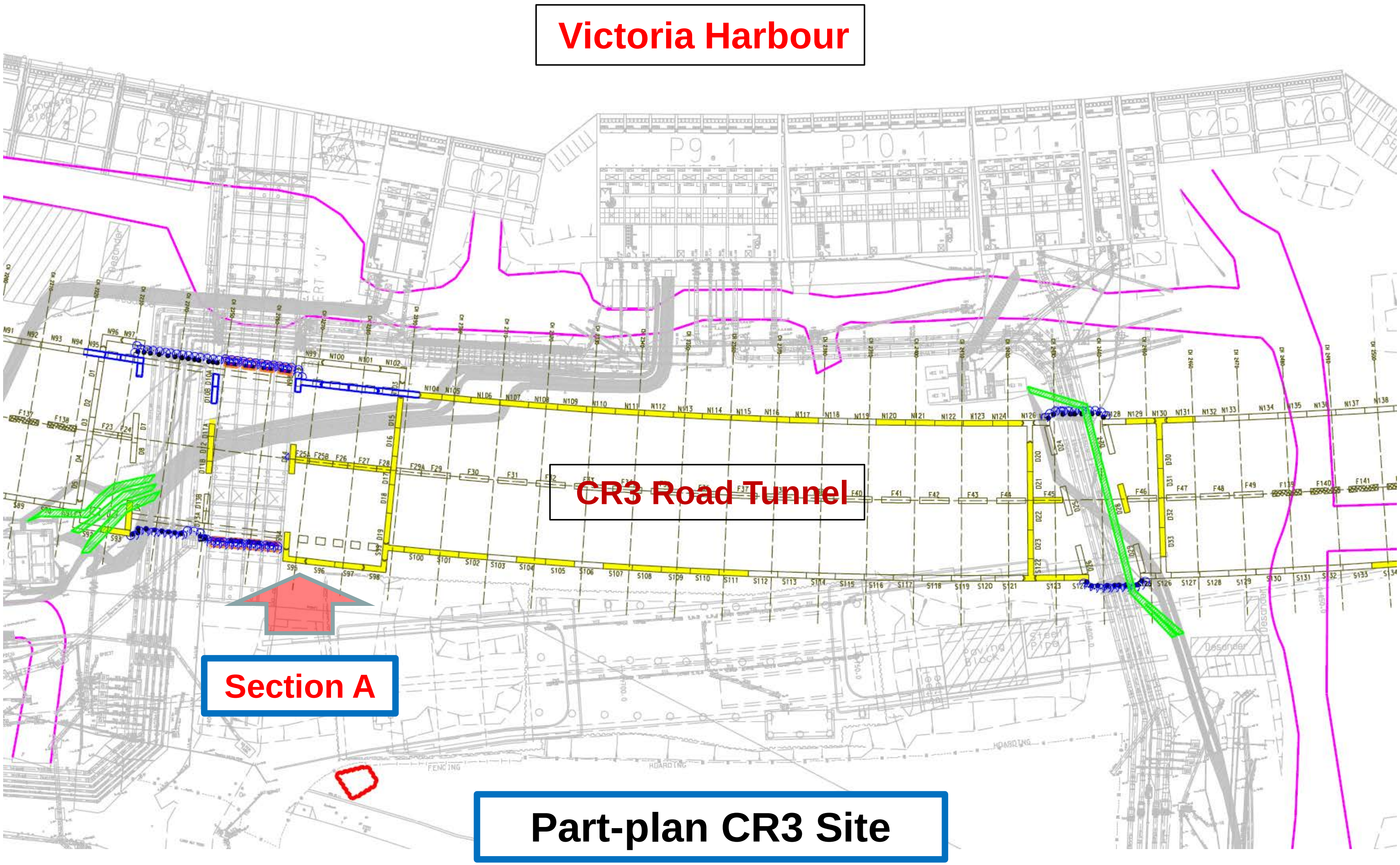
Introduction

- When the CWB road tunnel had been instructed, the 4-cell box culvert and cooling mains crossing the top of the road tunnel in the original Contract had been constructed and installed.
- Driving of continuous D-wall or piles for the cut and cover construction will be difficult.
- Discontinuous pre-bored H-piles and continuous 2.1 m dia. jet grouting columns were installed to support the cut and cover construction and provide the water cut-off required.

Vertical watertightness



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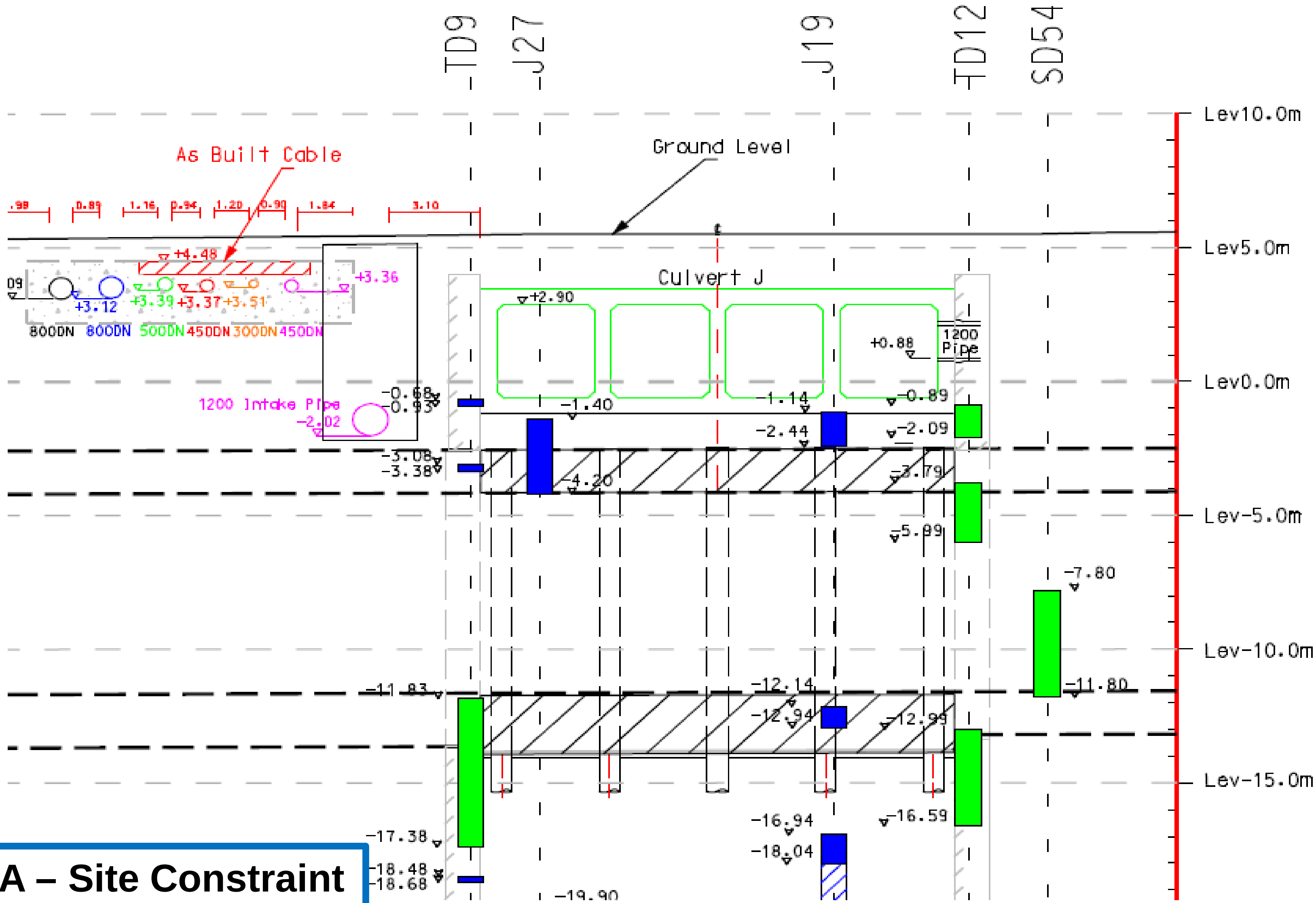
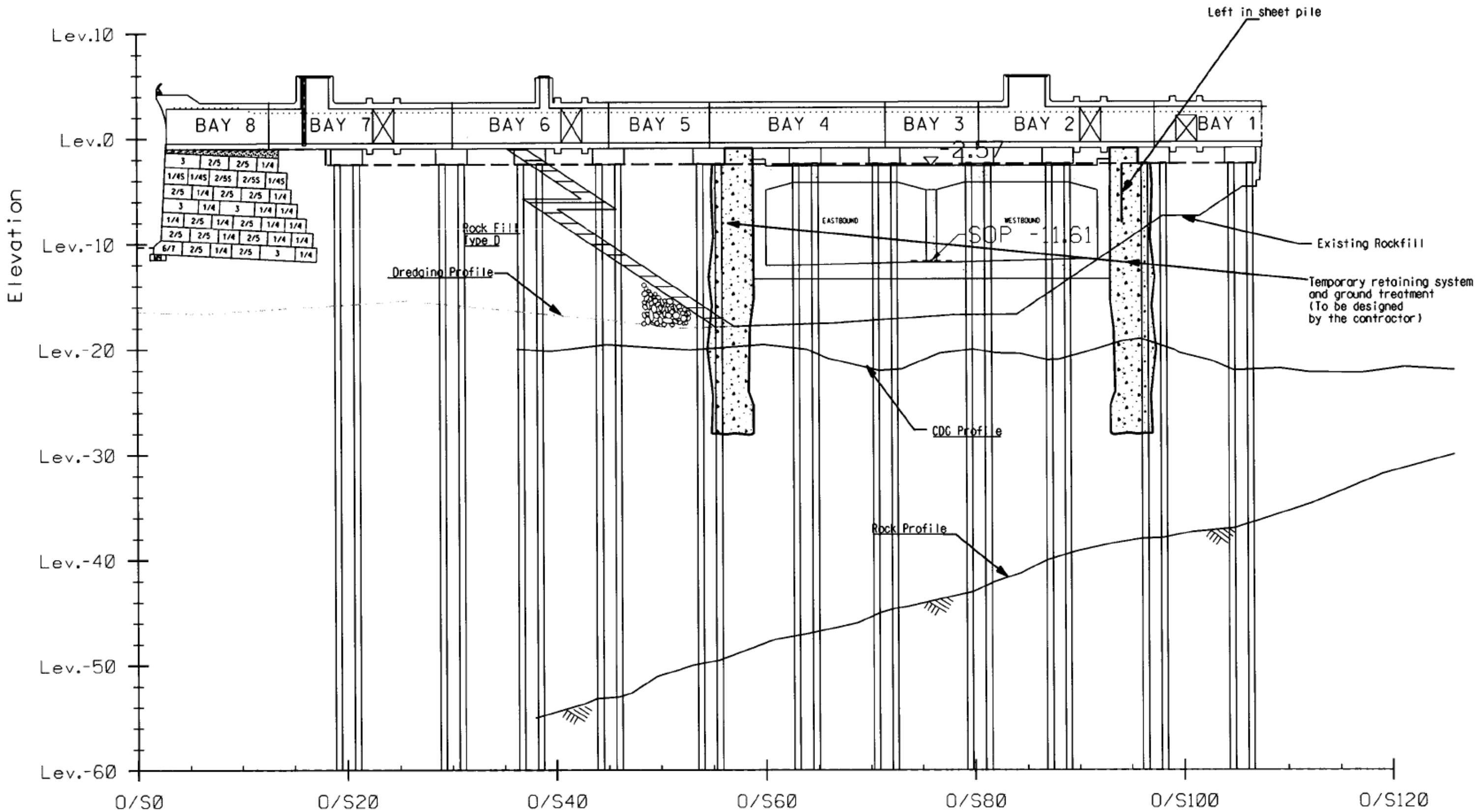


Section A – Site Constraint



Proposed cut-off as per Engineer's requirements

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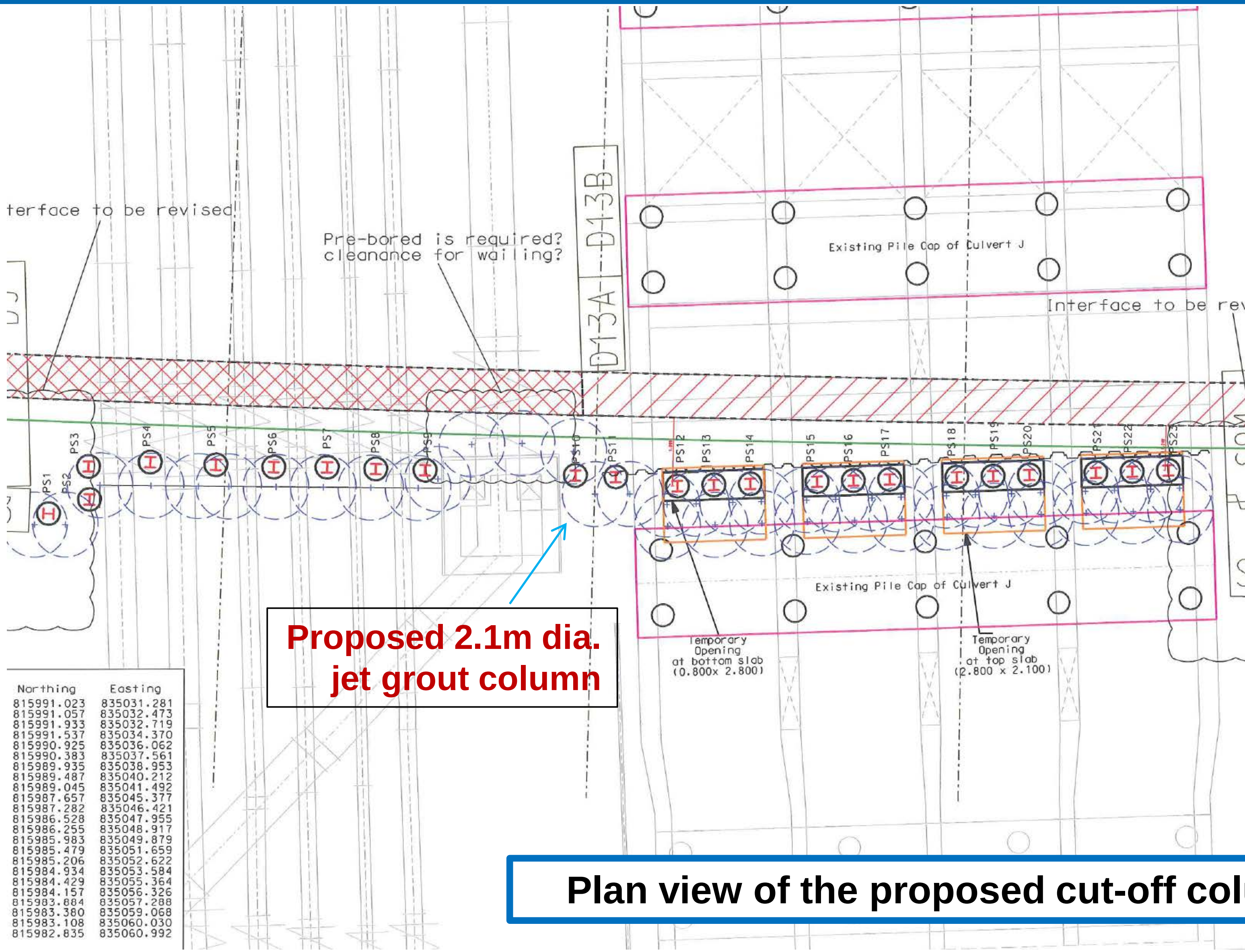
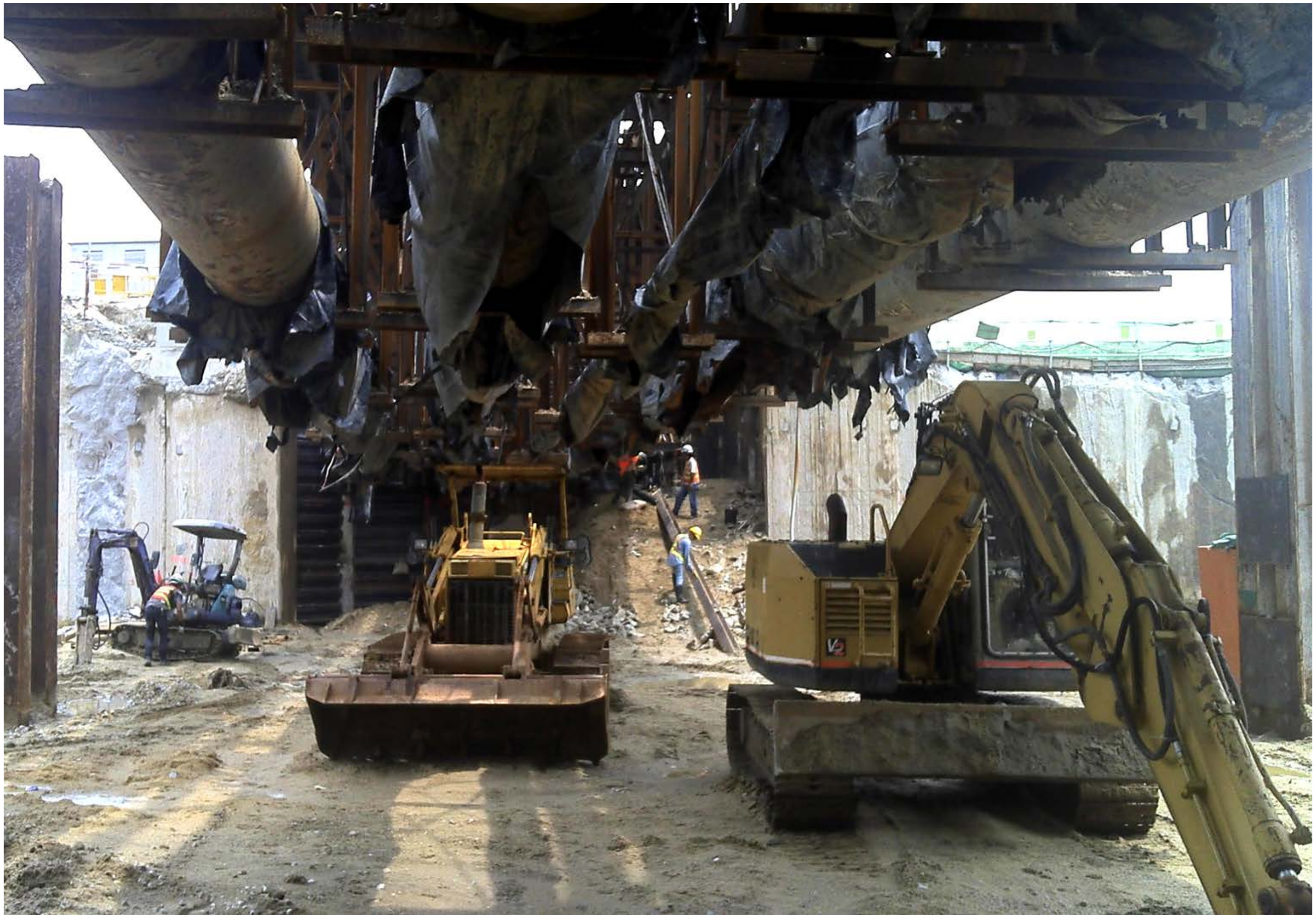


Northing	Easting
815991.023	835031.281
815991.057	835032.473
815991.933	835032.719
815991.537	835034.370
815990.925	835036.062
815990.383	835037.561
815989.935	835038.953
815989.487	835040.212
815989.045	835041.492
815987.657	835045.377
815987.282	835046.421
815986.528	835047.955
815986.255	835048.917
815985.983	835049.879
815985.479	835051.659
815985.206	835052.622
815984.934	835053.584
815984.429	835055.364
815984.157	835056.326
815983.884	835057.288
815983.380	835059.068
815983.108	835060.030
815982.835	835060.992

Plan view of the proposed cut-off columns

Preliminary full-scale trial field

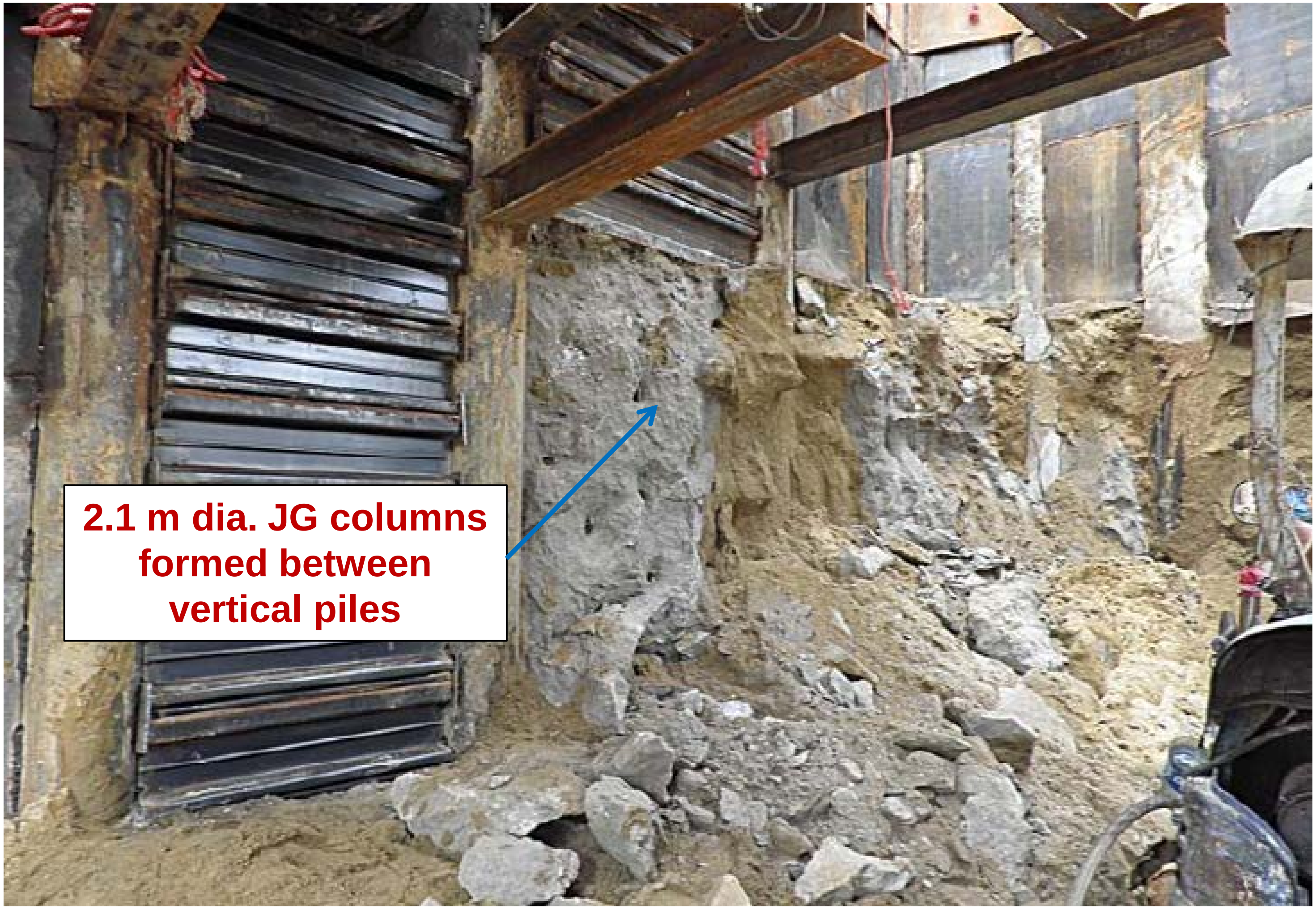
Whole area kept dry by cut-off columns to enable excavation to proceed



Whole area kept dry by cut-off JG columns to enable excavation to proceed

Vertical watertightness

JG columns formed between vertical piles and cooling mains



Excavation in progress

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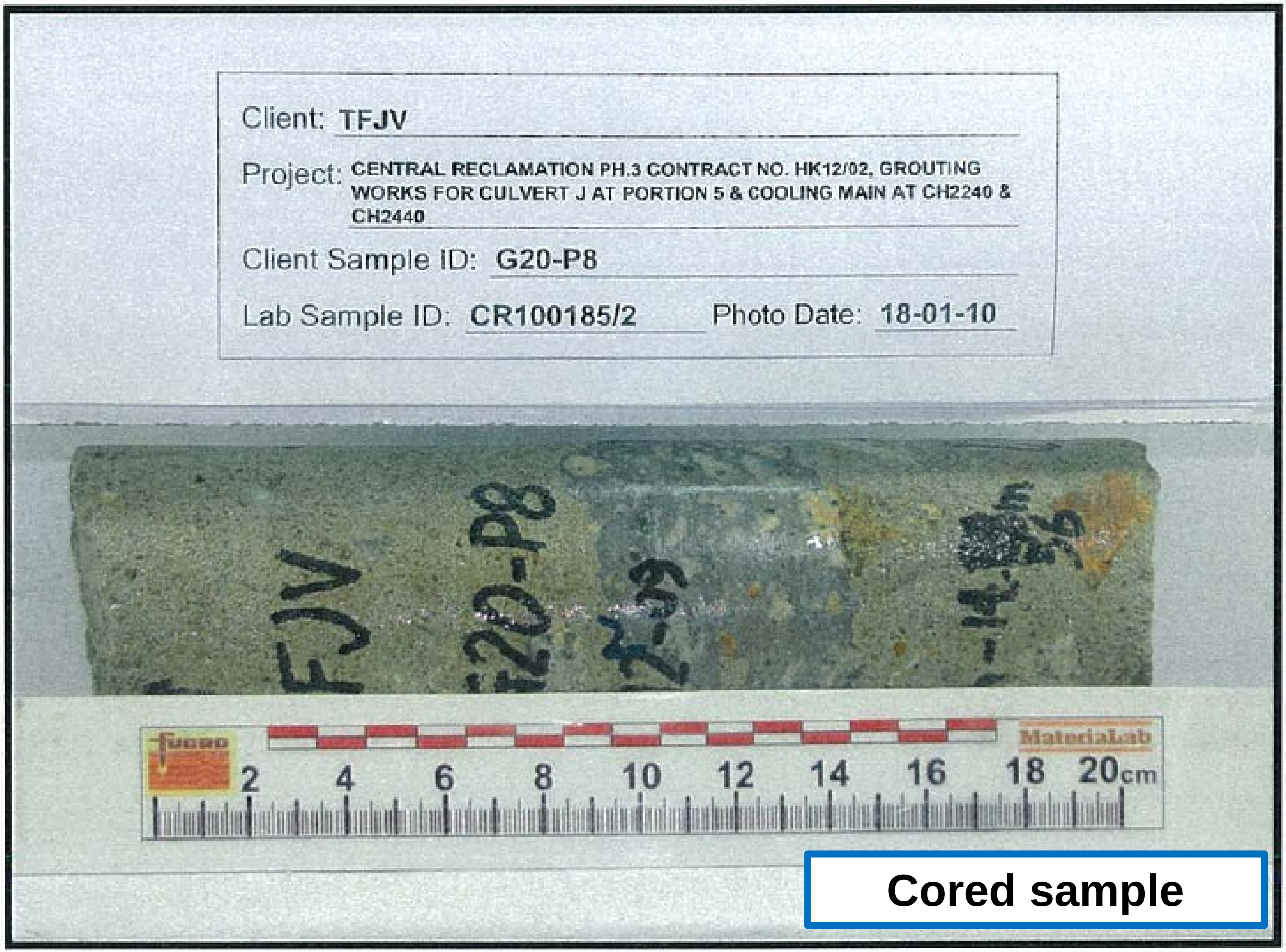

Cored sample

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Test Result

Date Received : 13/01/2010
Date Tested : 22/01/2010
Age of Test : 45 days
Condition as Received : Normal

Compaction of Concrete

Distribution of Materials : GOOD
Presence of Crack : NO
Classification of Voids -
Small Voids : Few
Medium Voids : Few
Large Voids : Few (no. of void = 0)

Length as Received : Min 215 mm
Max 255 mm
Length Before Capping : 91.4 mm
Length After Capping : 94.0 mm
Capping Material : SULPHUR COMPOUND
Location from Start of Drilling : 90-185 mm
Average Diameter : 83.1 mm
Length (after end preparation) / Diameter Ratio : 1.10

Description of Aggregate

Maximum Size : <5 mm
Particle Shape : ANGULAR

Reinforcement Size(mm) : -- -- -- -- -- -- --
Position (mm) : -- -- -- -- -- -- --
Spacing(mm) : -- -- -- -- -- -- --
Saturated Density : 2120 kg/m^3
(without reinforcement)

(volume by water displacement)

Max Load at Failure : 60.3 kN
Compressive Strength : 11.0 N/mm^2
Estimated In-situ Cube Strength : 10.5 N/mm^2

Type of Fracture : NORMAL

Test Method : CS1 : 1990 : Section 15 (AMD 1201, 1203 & 1205)

Remarks : * Sample details supplied by client

UCS laboratory test on cored sample

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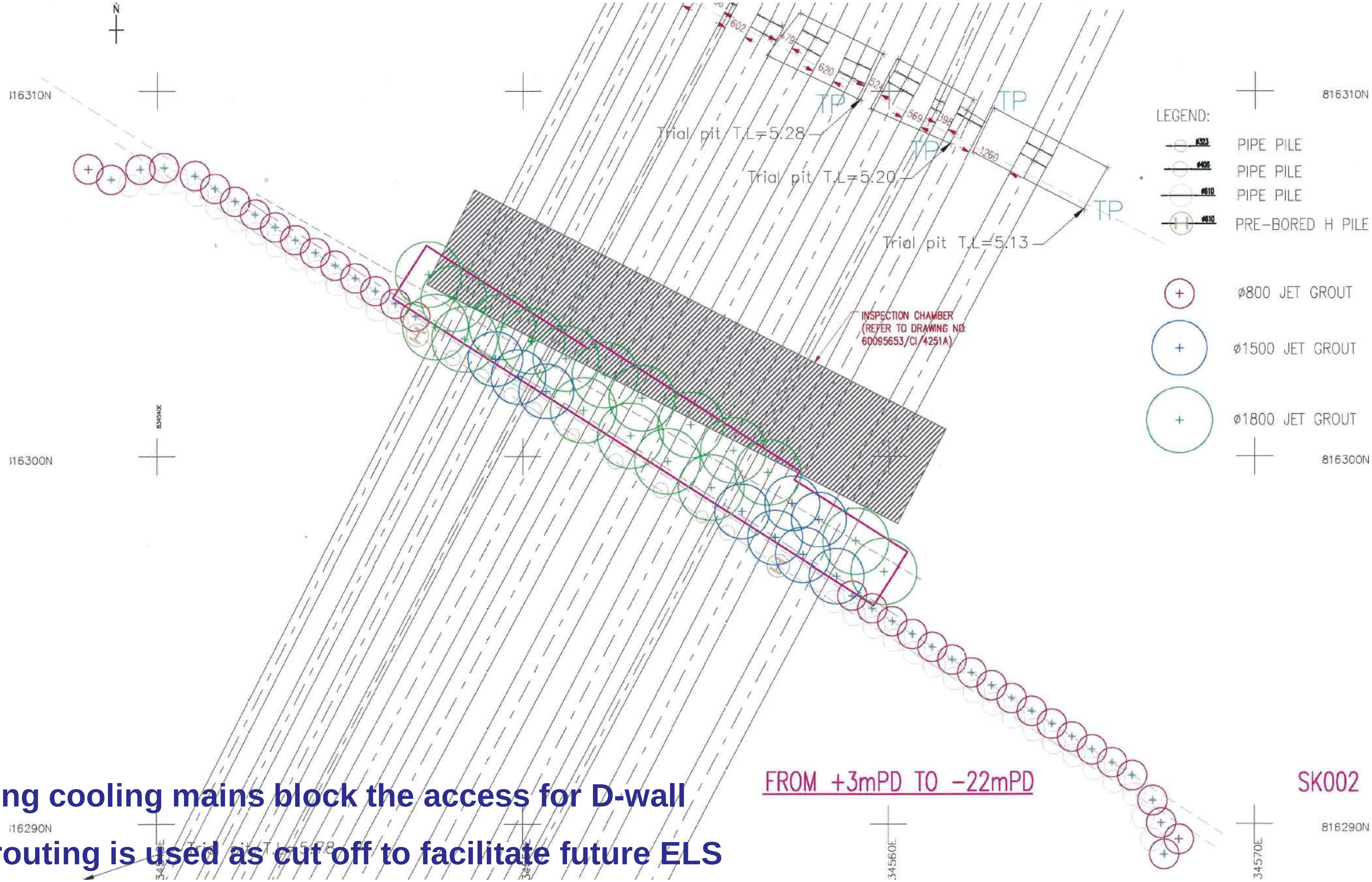
Test Results

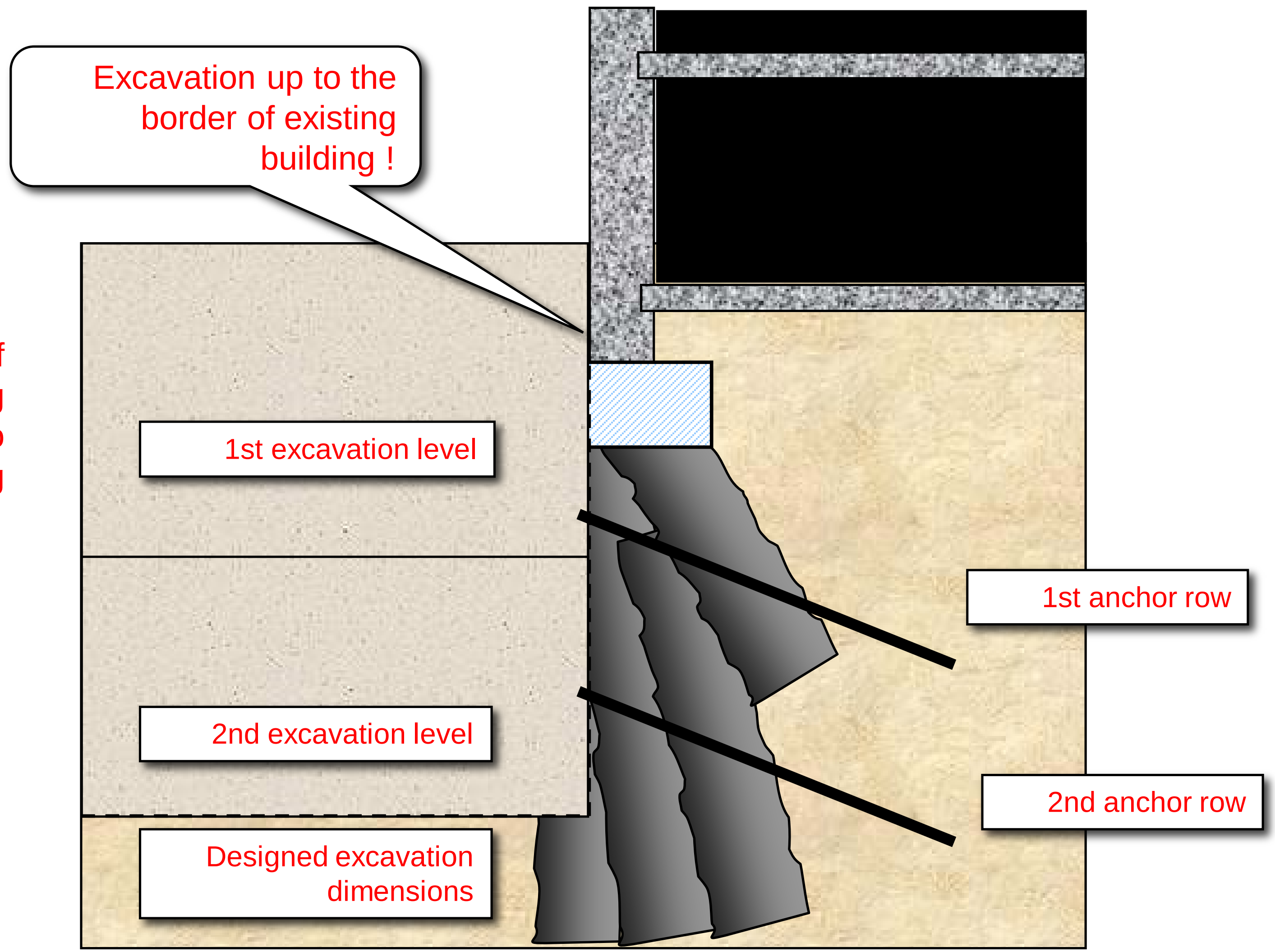
Lab. Sample I.D.	Pipet Reading (ml)		Elapsed Time T (sec.)	Permeation Q (m³)	Coefficient of Permeability K (m/s)
	Start	End			
CN90479/1	3.10	1.15	600	3.25×10^{-9}	1.148×10^{-8}
	3.10	1.10	600	3.33×10^{-9}	1.118×10^{-8}
	3.10	1.05	600	3.42×10^{-9}	1.207×10^{-8}
	3.10	1.10	600	3.33×10^{-9}	1.178×10^{-8}
	3.10	1.10	600	3.33×10^{-9}	1.178×10^{-8}
				Average	1.178×10^{-8}

Permeability laboratory test on cored sample



- Existing cooling mains block the access for D-wall
- Jet grouting is used as cut off to facilitate future ELS

Protection of existing buildings and structures



Over-profile of jet grouting columns has to be milled during excavation!

TREVIGroup

Project: **MTR 1109 – Stations and Tunnels of Kowloon City Section**

Main Contractor: **Samsung – Hsin Chong JV**

Scope of Works: **Jet Grouting as soil improvement to avoid settlements on the existing building and structures adjacent the road**

Progress: **Job started in December 2013 and was completed in May 2014**

Introduction

- Samsung His Chong JV had been awarded a contract for the construction of MTR stations and tunnels of the Kowloon City Section of the Shatin to Central Link line.
- Part of the tunnel are below To Kwa Wan Road and a diaphragm wall was installed to prevent settlement of the building along the road.
- Jet Grouting was used to: stop the settlements measured during construction of the diaphragm wall and to prevent any settlement during the removal of old piles below the highway.

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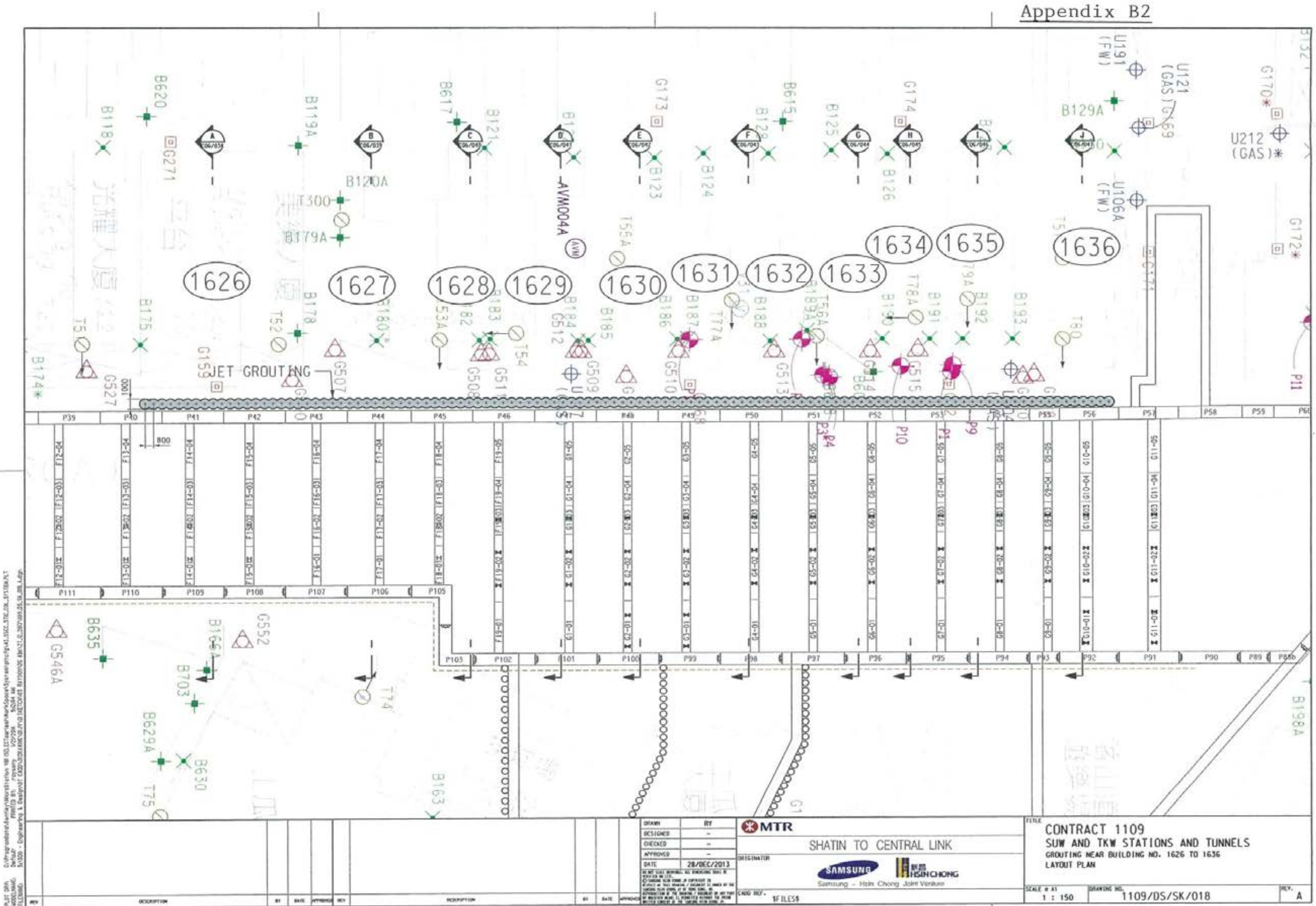

Appendix B2
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
JET GROUTING
AVM004A
B129A
U212
(GAS)
DATE 28/DEC/2013
MTR
SHATIN TO CENTRAL LINK
SAMSUNG
HSIN CHONG
Samsung - Hsin Chong Joint Venture
CONTRACT 1109
SUW AND TKW STATIONS AND TUNNELS
GROUTING NEAR BUILDING NO. 1626 TO 1636
LAYOUT PLAN
SCALE @ A1
1 : 150
DRAWING NO.
1109/DS/SK/018
REV.
A

Protection of existing buildings and structures

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Protection of existing buildings and structures

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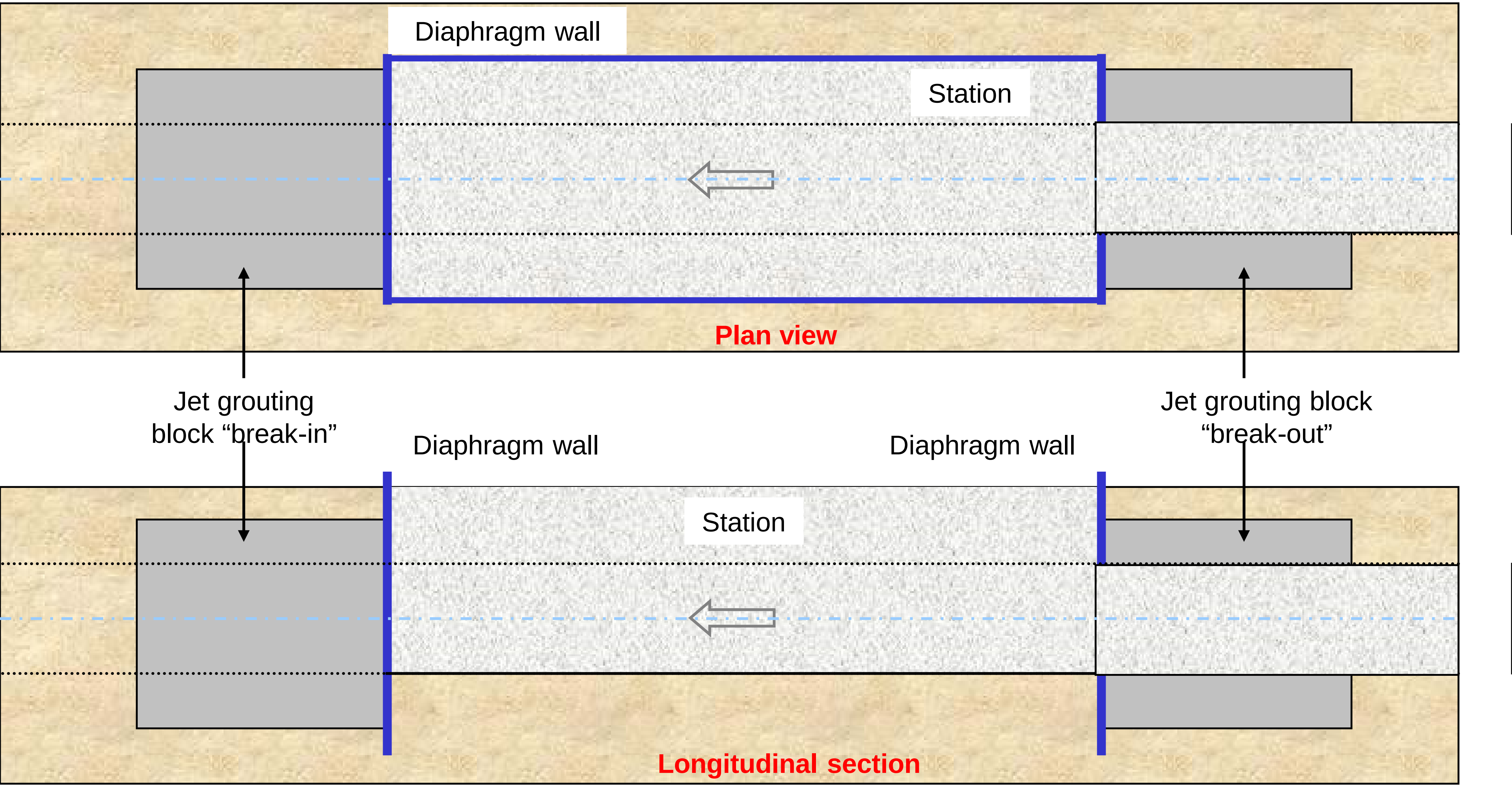
TBM break-in and break-out



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Project: **Lai Chi Kok Drainage Tunnel**

Consultant: **AECOM**

Main Contractor: **Leighton-John Holland JV**

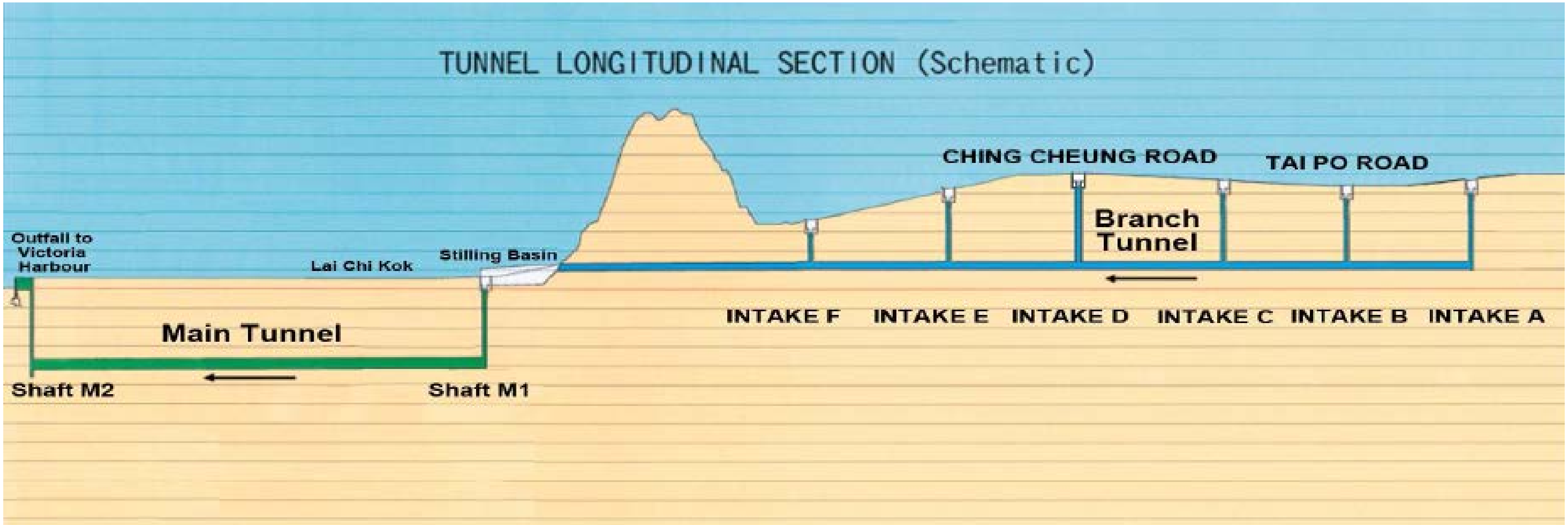
Scope of Works: **Jet Grouting as soil improvement at tunnel break-out**

Progress: **Job started in October 2010 and was completed in March 2011**

Introduction

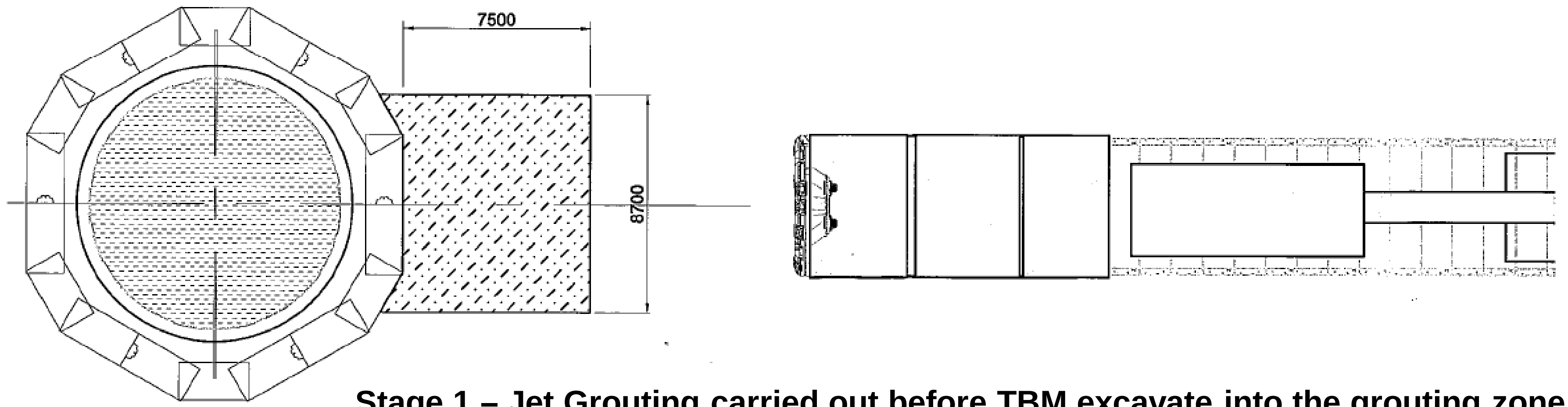
- Leighton John Holland JV had been awarded a contract to construct the Lai Chi Kok Drainage Tunnel
- The tunnel outfall will be at the shaft M2
- The tunnel will be constructed by TBM and break out at M2 whereas site investigation shows that the soil at M2 is of not adequate strength and high permeability.
- Horizontal pressure was designed by the LJHJV as the improvement scheme but TFJV considered jet grouting being a more effective scheme and was awarded the sub-contract based on jet grouting method.

Site General Layout

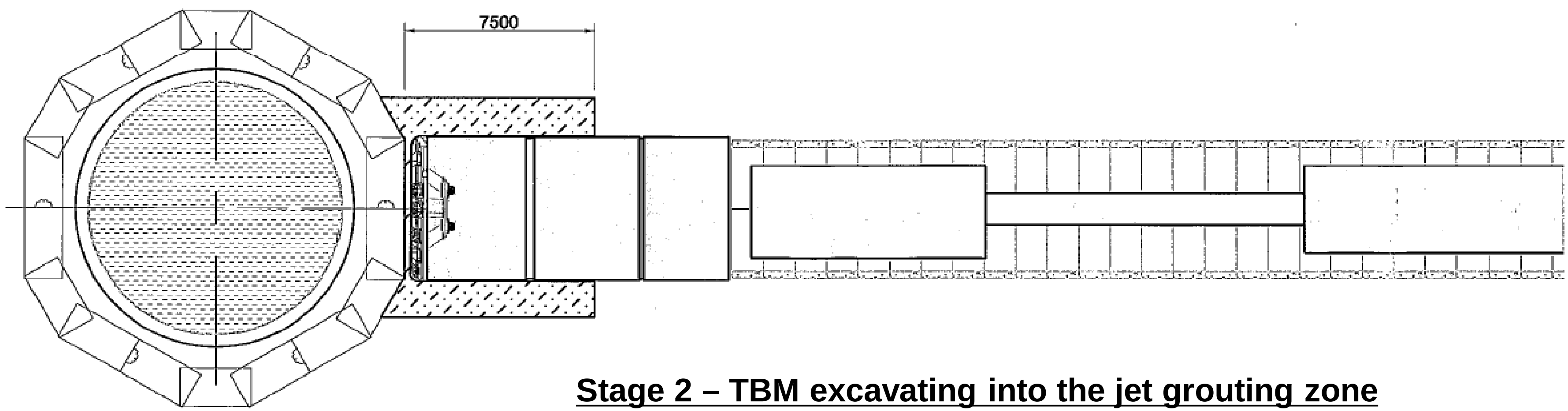


Tunnel Longitudinal Profile

Location of Outfall at Shaft M2



Stage 1 – Jet Grouting carried out before TBM excavate into the grouting zone



Stage 2 – TBM excavating into the jet grouting zone

Requirement for Jet Grouting work at tunnel breakout (1 of 2)

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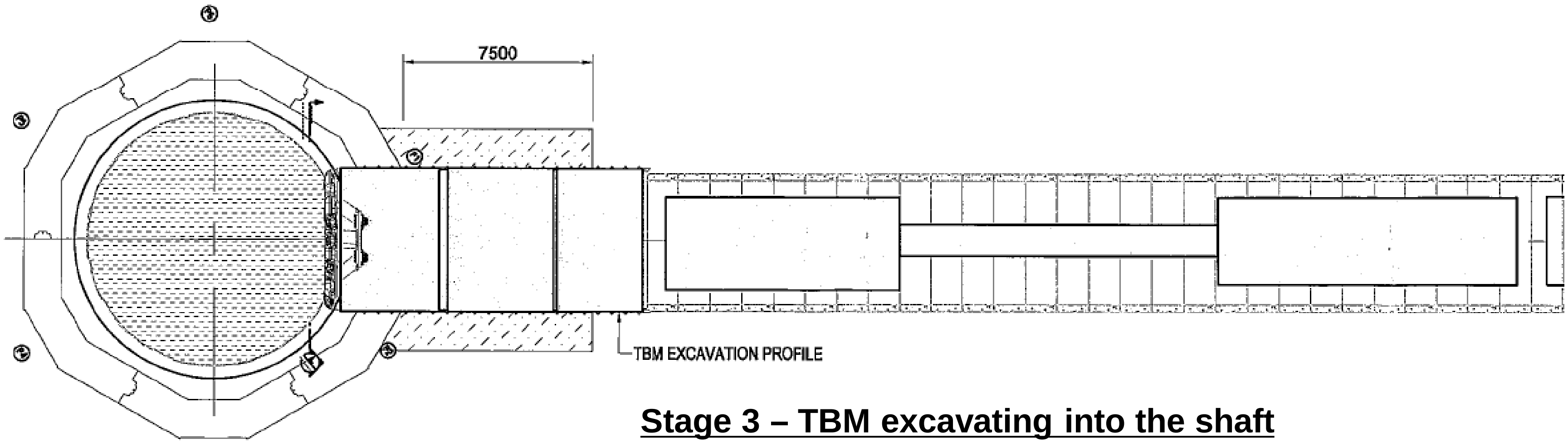
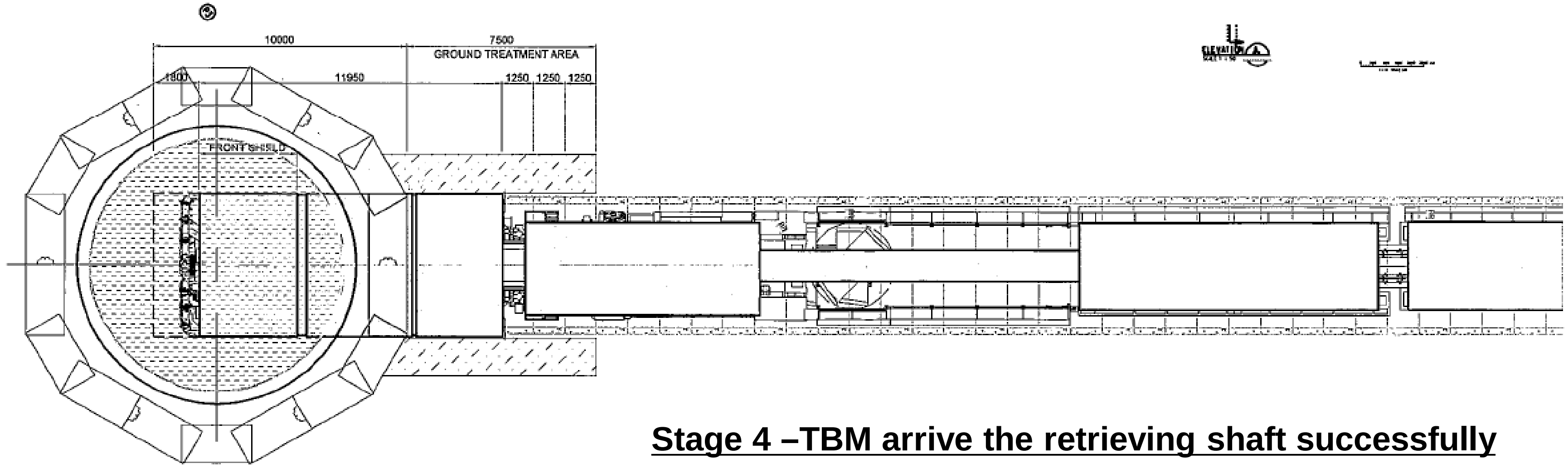
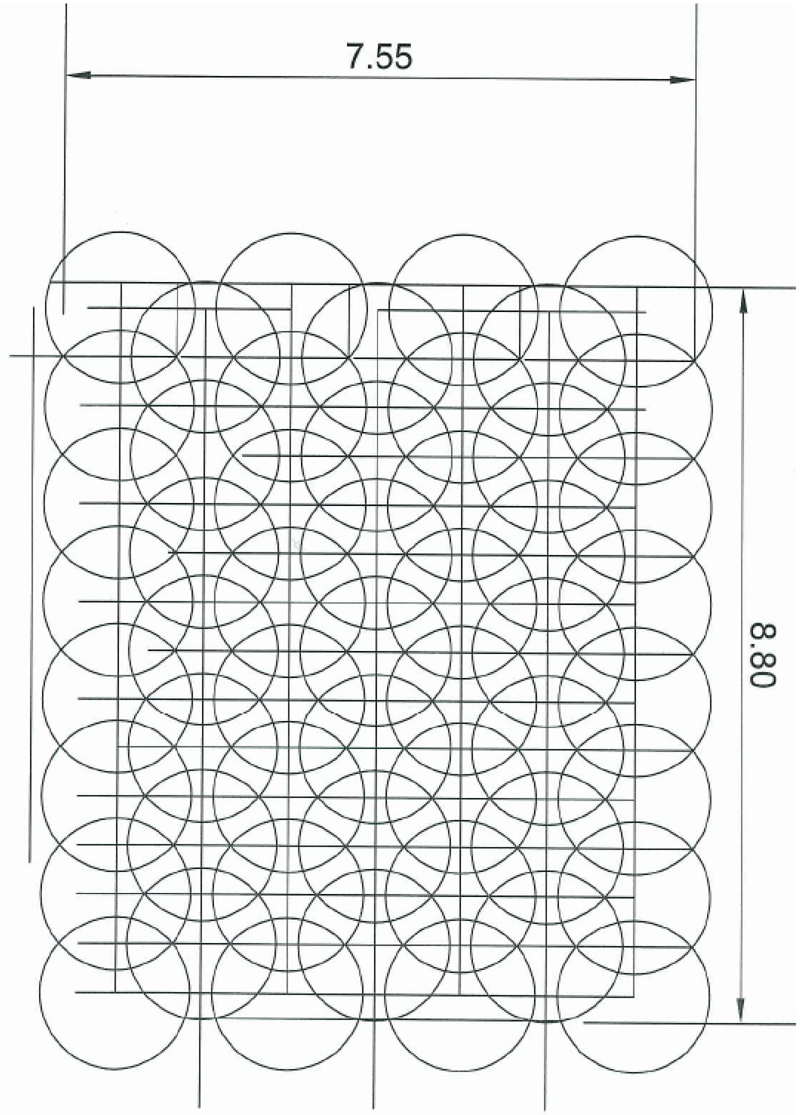


Stage 3 – TBM excavating into the shaft



Stage 4 –TBM arrive the retrieving shaft successfully

Requirement for Jet Grouting work at tunnel breakout (2 of 2)



Proposed 1.8 m diameter jet grouting columns with the spacing shown on the sketch to cover the required treatment area.

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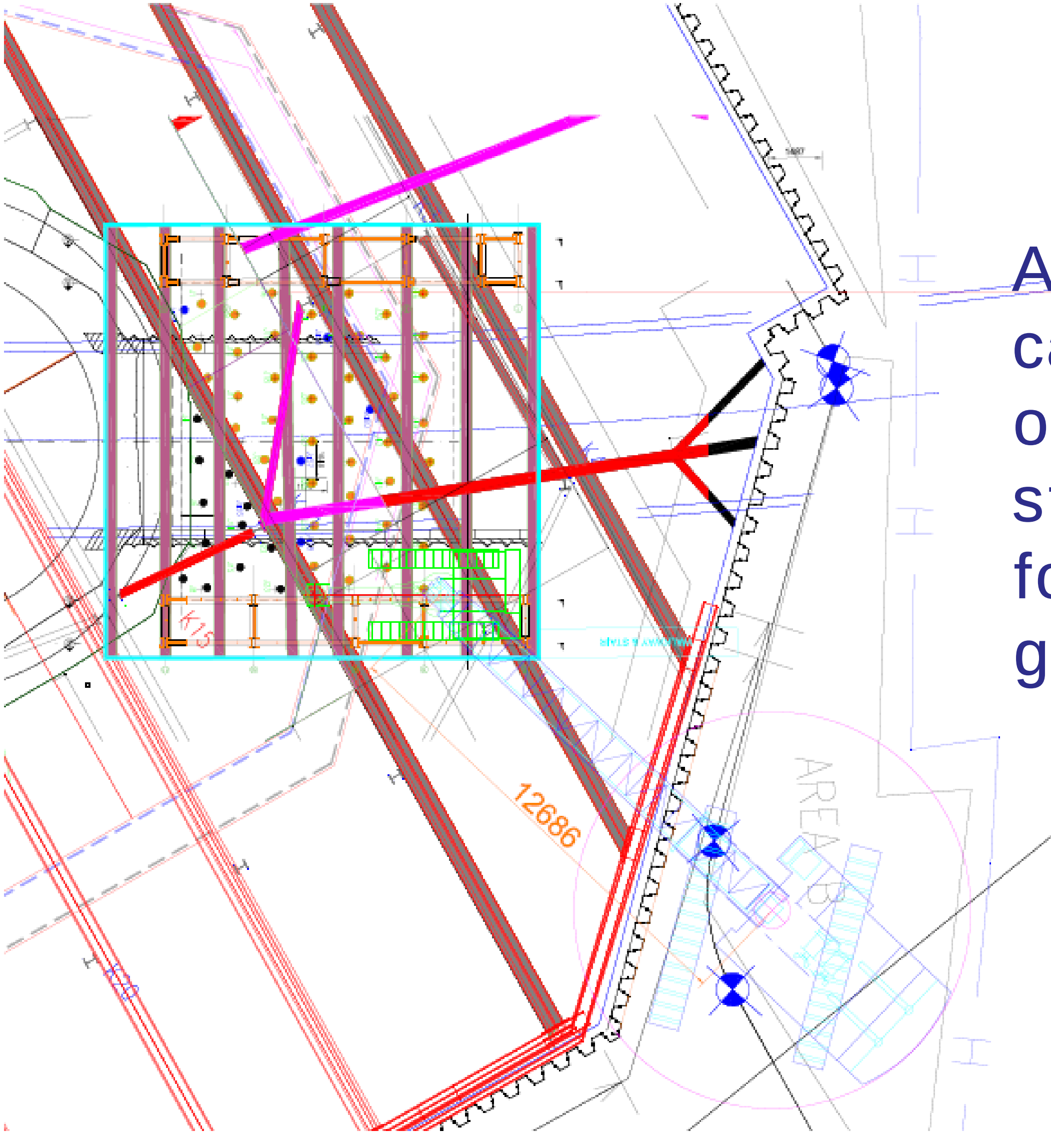


As Jet Grouting needed to be carried out at the same time of the outfall construction, a steel platform was erected for supporting the jet grouting rig.

Steel platform erected for supporting the jet grouting rig

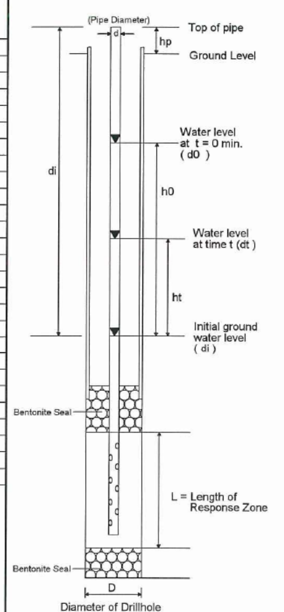
In-situ permeability test

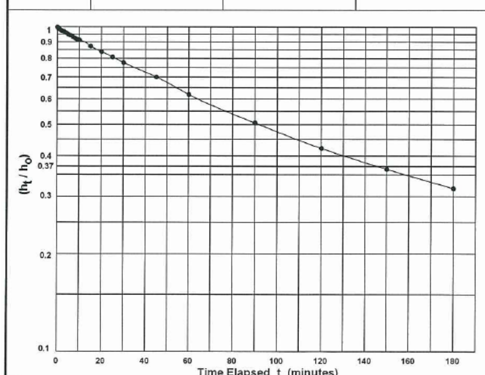
VIBRO

FALLING HEAD PERMEABILITY TEST RECORD SHEET

Contractor :	VIBRO (H.K.) LIMITED	Drillhole No. :	CH03
Contract No. :	J201114e	Date of Test :	16/03/2011
Works Order No. :	N/A	Ground Level :	+ 5.60 mPD
Project :	3 Coring Works at Grount Column at Lai Chi Kok	Test No. :	1-1
		Co-ordinates :	E N
Initial Water Level Before Test :	5.88 m below G. L.	Depth of Test :	38.78m to 40.28m
Tested / Supervised By :	C. H. Yeung	Checked By :	E. Leung

Time Elapsed, t (minutes)	Depth of Water from top of pipe dt (m)	ht ht = di - dt (m)	ht / h0 (h0 = di - d0)
0	0.00	7.55	1.00
0.25	0.03	7.52	1.00
0.5	0.05	7.50	0.99
0.75	0.10	7.45	0.99
1	0.12	7.43	0.98
1.5	0.16	7.39	0.98
2	0.20	7.35	0.97
3	0.24	7.31	0.97
4	0.31	7.24	0.96
5	0.39	7.16	0.95
6	0.44	7.11	0.94
7	0.51	7.04	0.93
8	0.58	6.97	0.92
9	0.64	6.91	0.92
10	0.67	6.88	0.91
15	0.96	6.59	0.87
20	1.22	6.33	0.84
25	1.45	6.10	0.81
30	1.69	5.86	0.78
45	2.26	5.29	0.70
60	2.88	4.67	0.62
90	3.73	3.82	0.51
120	4.36	3.19	0.42
150	4.80	2.75	0.36
180	5.15	2.40	0.32





d = 0.038 m
D = 0.101 m
L = 1.50 m
hp = 1.67 m
di = 7.55 m

Where :

Area = $A = \frac{d^2 \pi}{4}$ = 0.0011341 (in metre^2)

Intake Factor = F (in metres)

$$F = \frac{2.4 \pi L}{\ln \left[1.2\frac{L}{D} + \sqrt{1 + \left(1.2\frac{L}{D}\right)^2} \right]} = 3.16$$

Note : T is time where ht / h0 = 0.37

T = 8760 sec

Permeability $k = \frac{A}{FT}$

$k = 4.10 \times 10^{-8}$ m/sec

Material Surrounding Response Zone :

Filter Material :
Sand Filter

Permeability test results

Cored samples

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Maintenance Chamber

Views from inside the TBM's head

SCL 1107 – Diamond Hill to Kai Tak Tunnels

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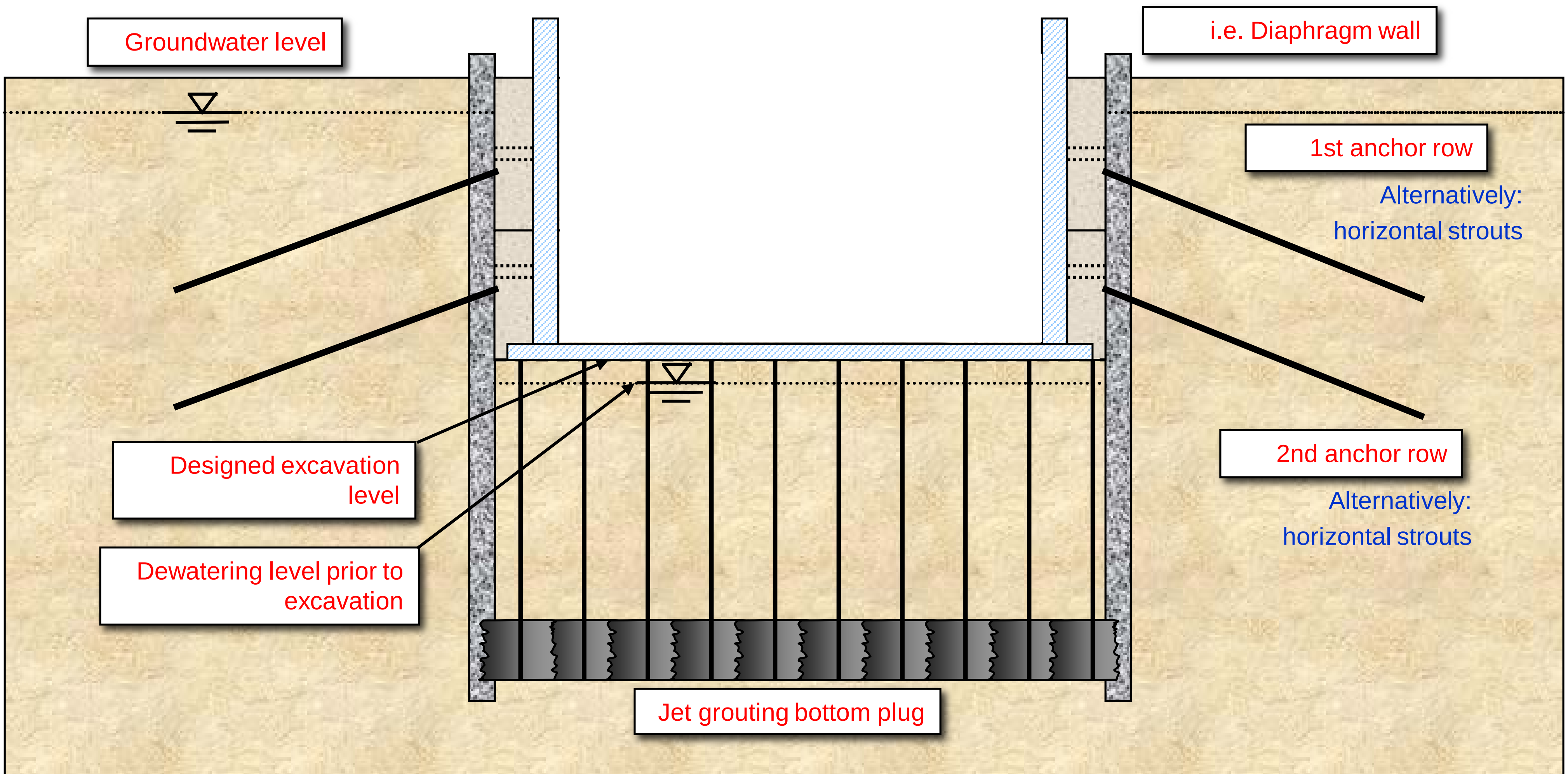


Cross section through a typical excavation pit

***Project*: HKZMB – Hong Kong Boundary Crossing Facilities – Passenger Crossing Building**

***Consultant*: Golder Associates.**

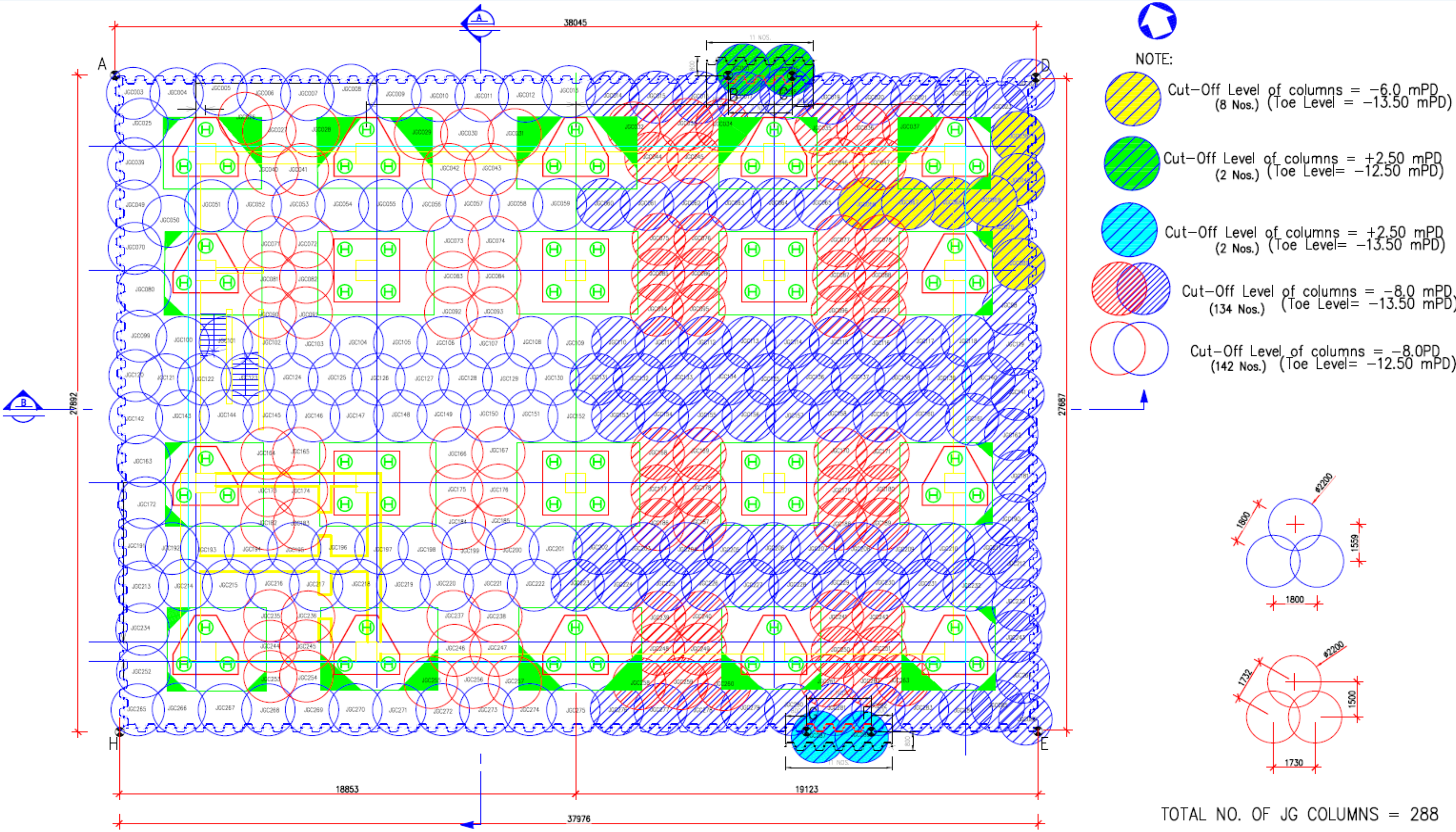
***Main Contractor*: Leighton–Chun Wo JV.**

***Scope of Works*: Jet Grouting as horizontal bottom plug for the seawater pump house.**

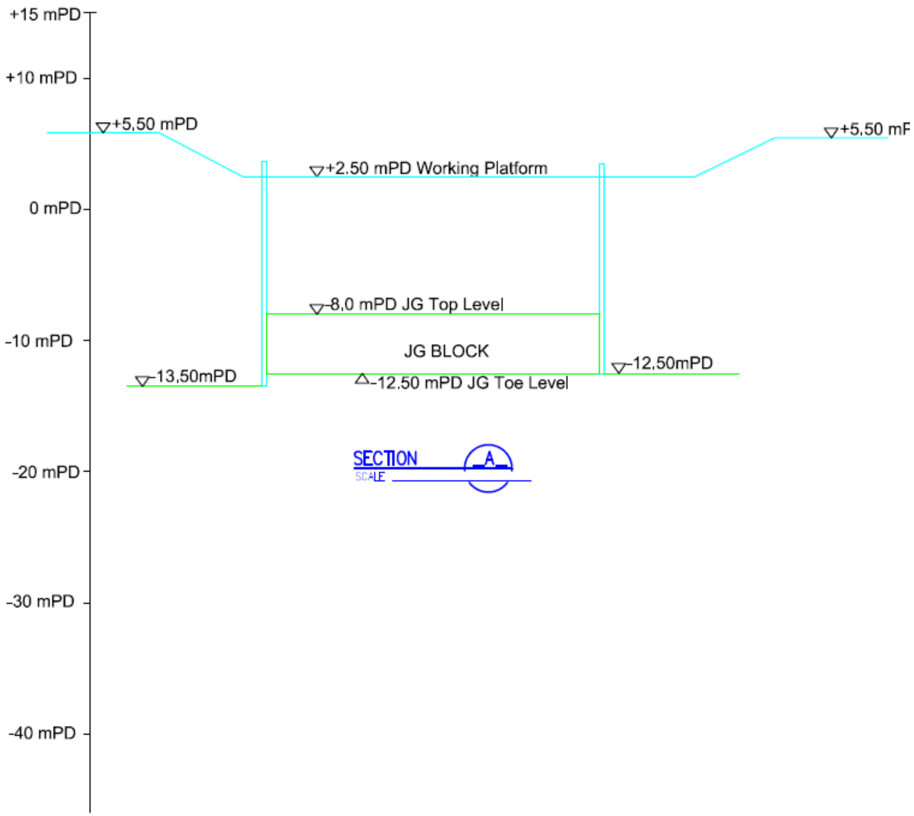
***Progress*: Job started in June 2016 and was completed in September 2016.**

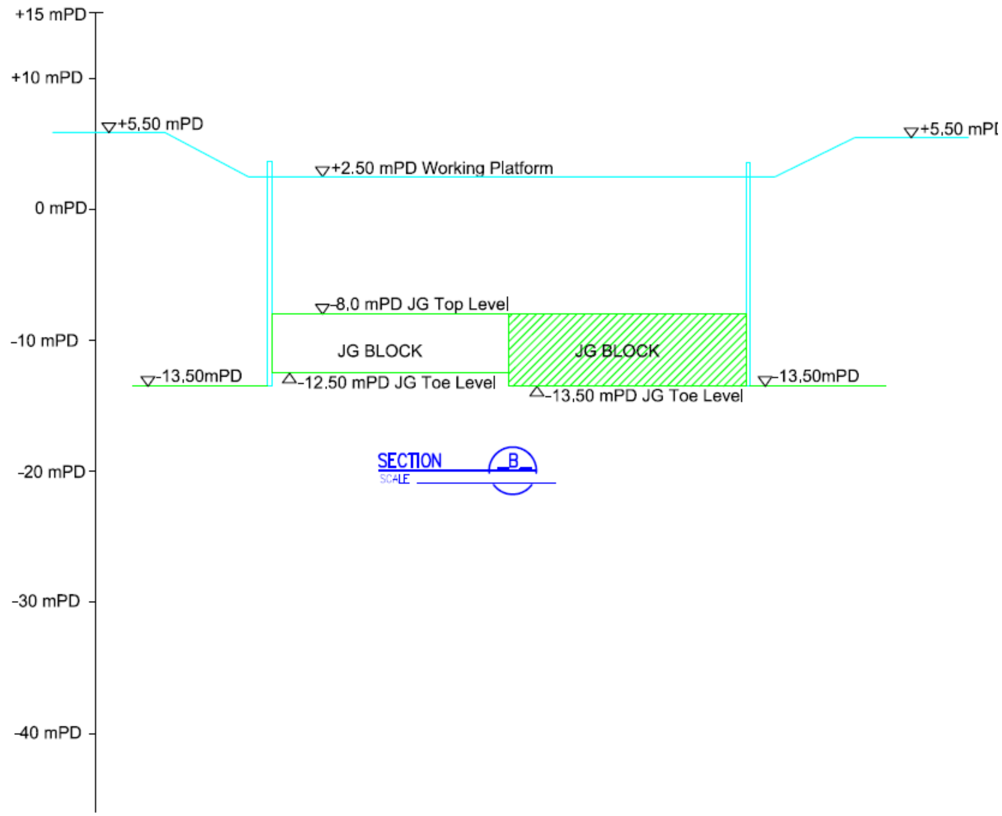
Introduction

- Leighton-Chun Wo JV had been awarded a contract to construct the Passenger Clearance Building for the Hong Kong–Zhuhai–Macau Bridge – HK Boundary Crossing Facilities.
- Use of Jet Grouting was deemed the best solution to provide a watertight bottom slab below the seawater pumphouse.


38045
A
B
D
E
H
27892
27687
18853
19123
37976
11 NOS.
NOTE:
Cut-Off Level of columns = -6.0 mPD (8 Nos.) (Toe Level = -13.50 mPD)
Cut-Off Level of columns = +2.50 mPD (2 Nos.) (Toe Level= -12.50 mPD)
Cut-Off Level of columns = +2.50 mPD (2 Nos.) (Toe Level= -13.50 mPD)
Cut-Off Level of columns = -8.0 mPD (134 Nos.) (Toe Level= -13.50 mPD)
Cut-Off Level of columns = -8.0PD (142 Nos.) (Toe Level= -12.50 mPD)
1800
1559
1800
1732
1500
1730
TOTAL NO. OF JG COLUMNS = 288

Horizontal bottom plugs





Horizontal bottom plugs

Horizontal bottom plugs

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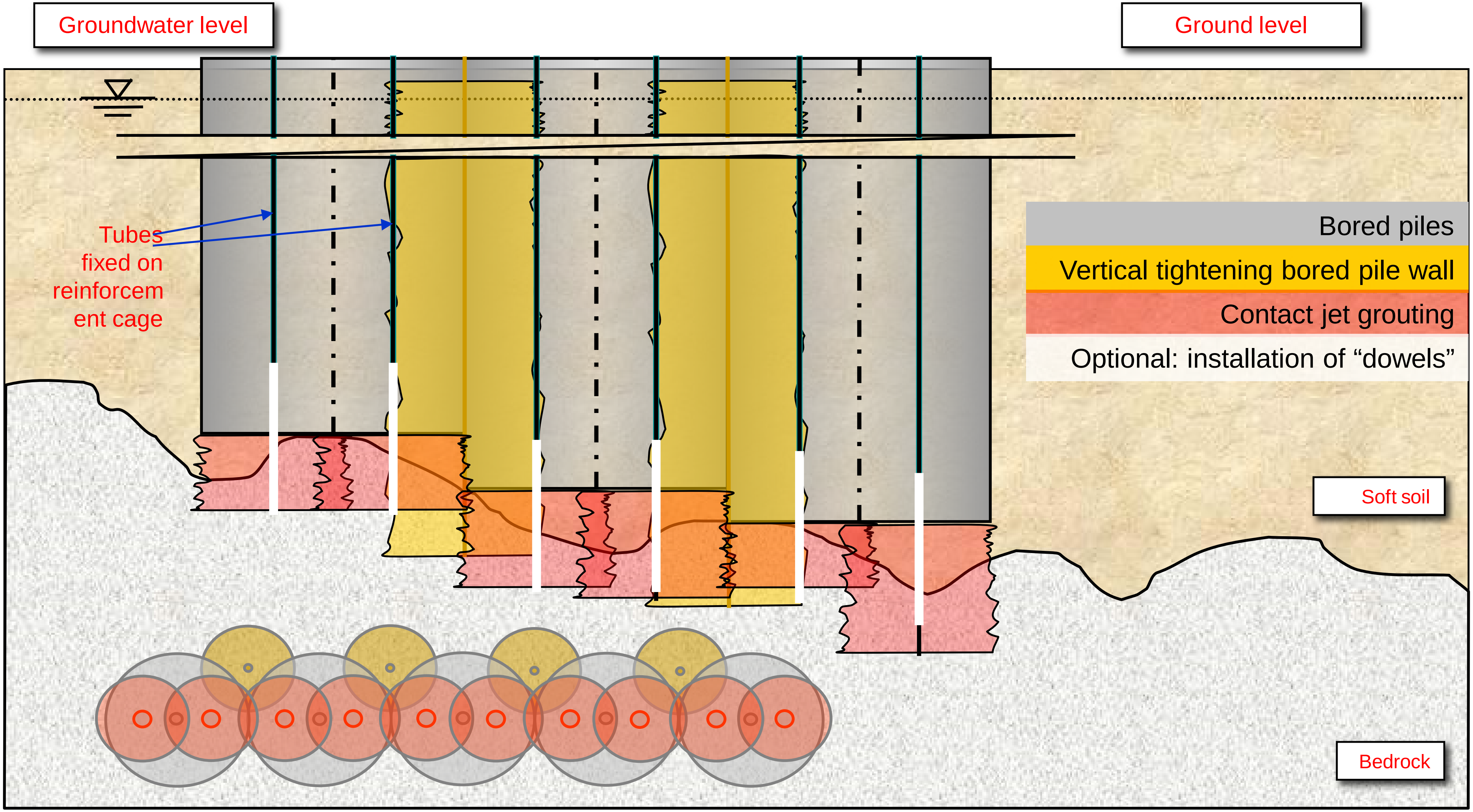
Watertight contact between piles and bedrock



Project: **HKZMB – HK Link Road – Section between Scenic Hill and HK Boundary Crossing Facilities**

Consultant: **ARUP**

Main Contractor: **CSCEC**

Scope of Works: **Jet Grouting as watertight contact to rock**

Progress: **Job started in July 2016 and was completed in August 2016**

Introduction

- China State Construction Engineering had been awarded a contract for the construction of the Section between Scenic Hill and HK Boundary Crossing Facilities of the HKZHMB.
- Jet Grouting was proposed and accepted to be used as watertight contact between the pile's toe and the bedrock.

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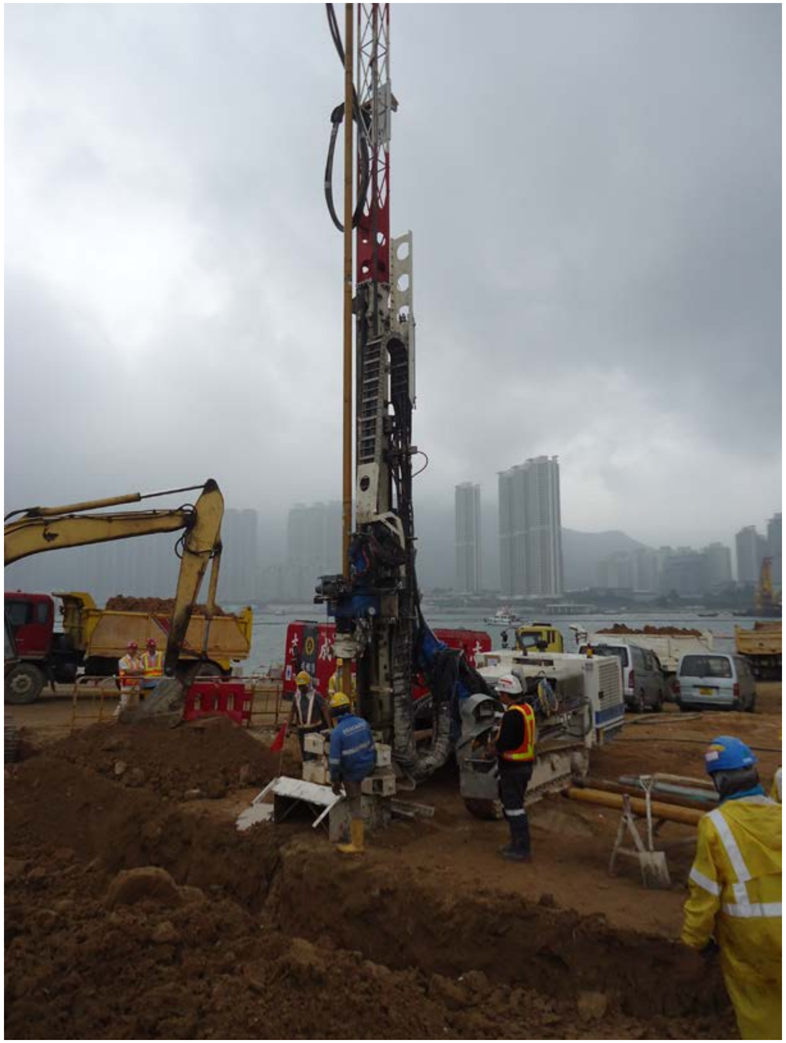
SLOW
慢駛
WORKS ACCESS
工地出入口
100m
一百米



MTR 810A – West Kowloon Terminus Station North

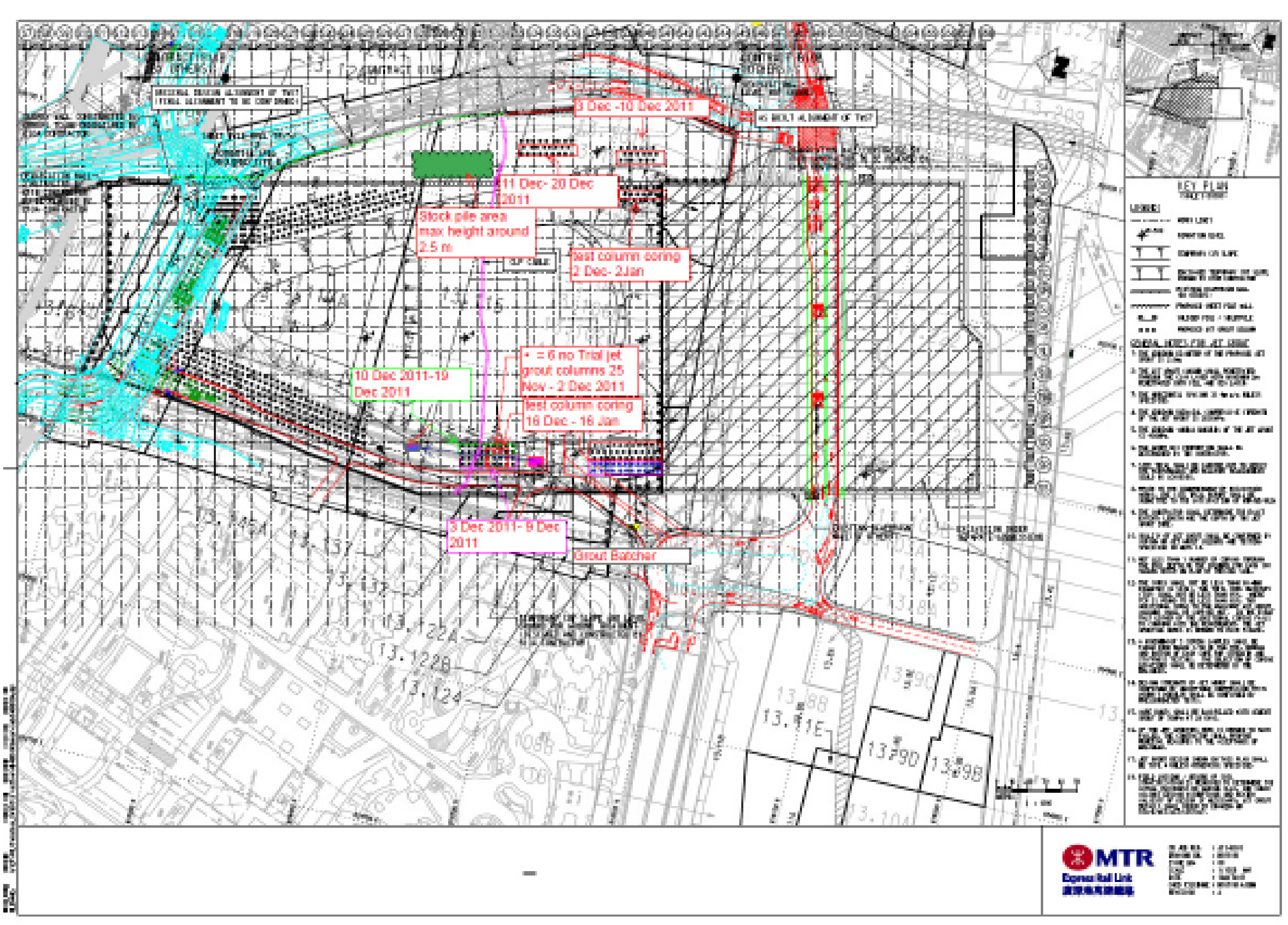
***Project*: MTR 810A – West Kowloon Terminus Station North**

***Main Contractor:* Leighton-Gammon JV**

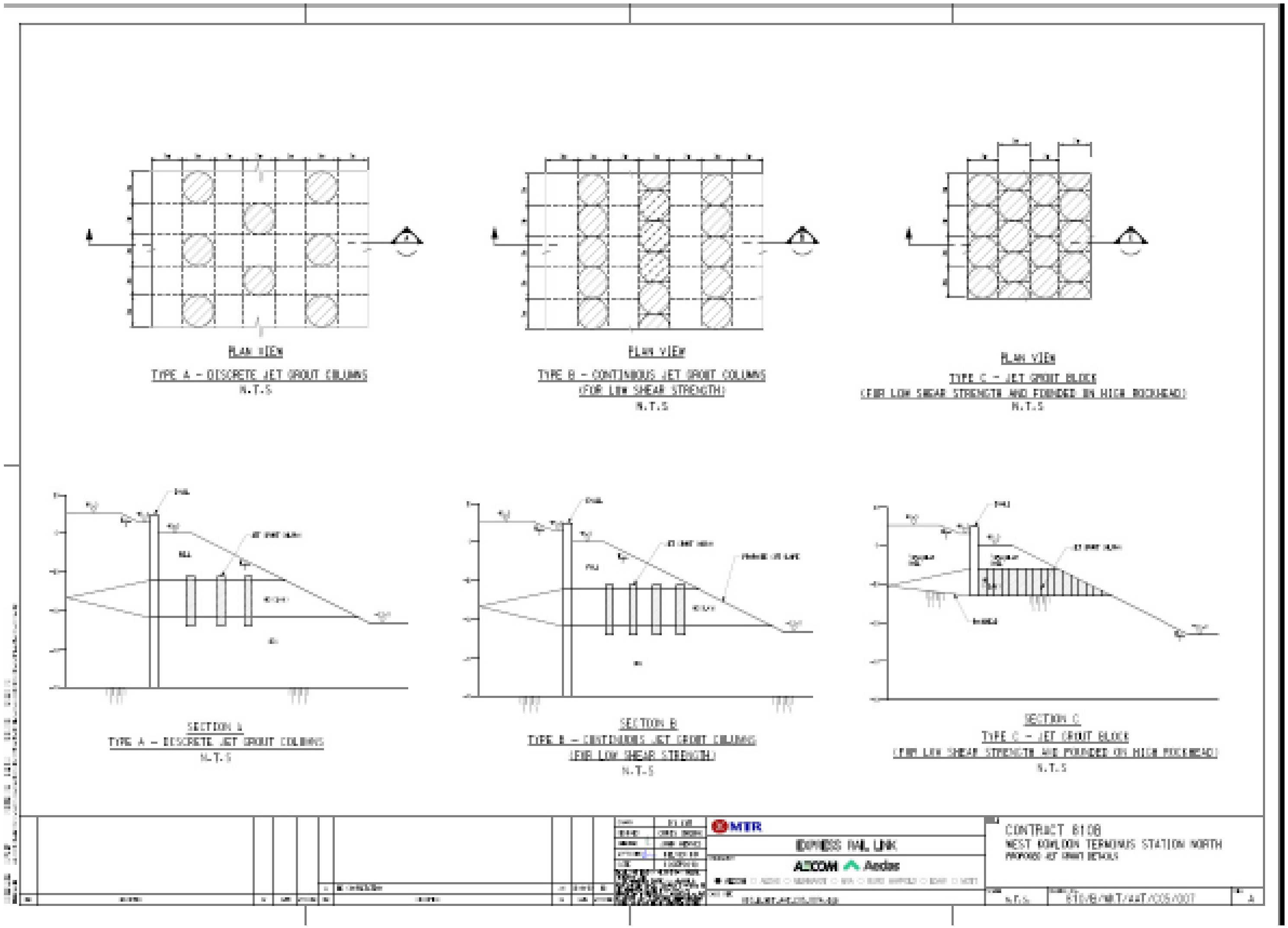
***Consultant:* Arup**

***Scope of Works*: Jet Grouting columns to stabilize a slope**

***Progress*: Job started in November 2011 and was completed in December 2012**


3 Dec -10 Dec 2011
11 Dec- 20 Dec 2011
Stock pile area max height around 2.5 m
test column coring 2 Dec- 2Jan
= 6 no Trial jet grout columns 25 Nov - 2 Dec 2011
10 Dec 2011-19 Dec 2011
test column coring 16 Dec - 16 Jan
3 Dec 2011- 9 Dec 2011
Grout Batcher
KEY PLAN
MTR
Express Rail Link

TREVIGroup


PLAN VIEW
TYPE A - DISCRETE JET GROUT COLUMNS
N.T.S
PLAN VIEW
TYPE B - CONTINUOUS JET GROUT COLUMNS
(FOR LOW SHEAR STRENGTH)
N.T.S
PLAN VIEW
TYPE C - JET GROUT BLOCK
(FOR LOW SHEAR STRENGTH AND FOUNDED ON HIGH ROCKHEAD)
N.T.S
SECTION A
TYPE A - DISCRETE JET GROUT COLUMNS
N.T.S
SECTION B
TYPE B - CONTINUOUS JET GROUT COLUMNS
(FOR LOW SHEAR STRENGTH)
N.T.S
SECTION C
TYPE C - JET GROUT BLOCK
(FOR LOW SHEAR STRENGTH AND FOUNDED ON HIGH ROCKHEAD)
N.T.S
MTR
EXPRESS RAIL LINK
AECOM
Aedas
CONTRACT 810B
WEST KOWLOON TERMINUS STATION NORTH


17/6/2012 13:51

Slope stabilization

Slope stabilization

Slope stabilization

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Improve mechanical characteristics of soft and loose soils

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Project: **HKZMB – HK Boundary Crossing Facilities – Reclamation Works**

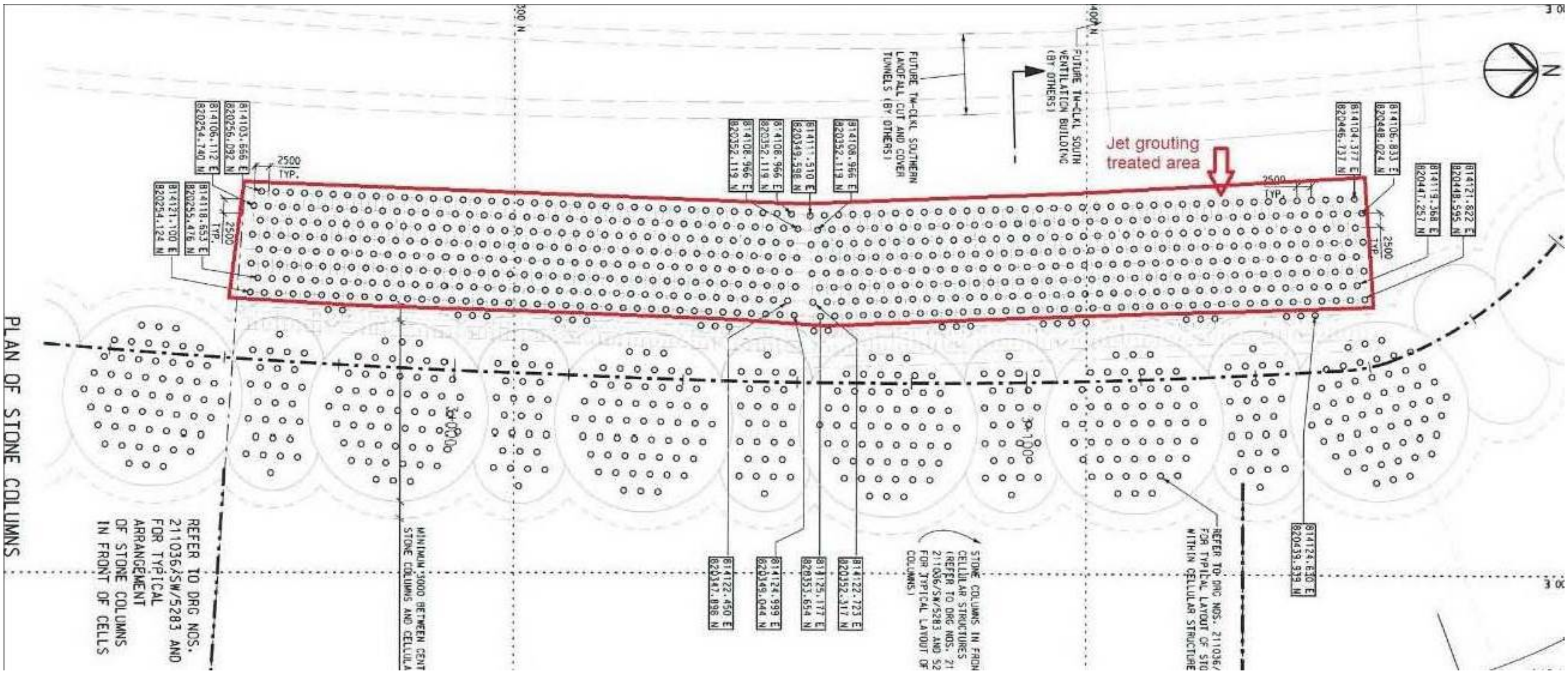
Main Contractor: **China Harbour Engineering Company Ltd.**

Scope of Works: **Jet Grouting to consolidate soft and loose soils under an artificial island**

Progress: **Job started in March 2015 and was completed in June 2015**

Introduction

- China Harbour Engineering Company Ltd. had been awarded a contract for the reclamation works for the HKZMB – HK Boundary Crossing Facilities.
- Jet Grouting has been adopted to consolidate soft and loose soils below the newly created island.


Jet grouting treated area
PLAN OF STONE COLUMNS

Improve mechanical characteristics of soft and loose soils

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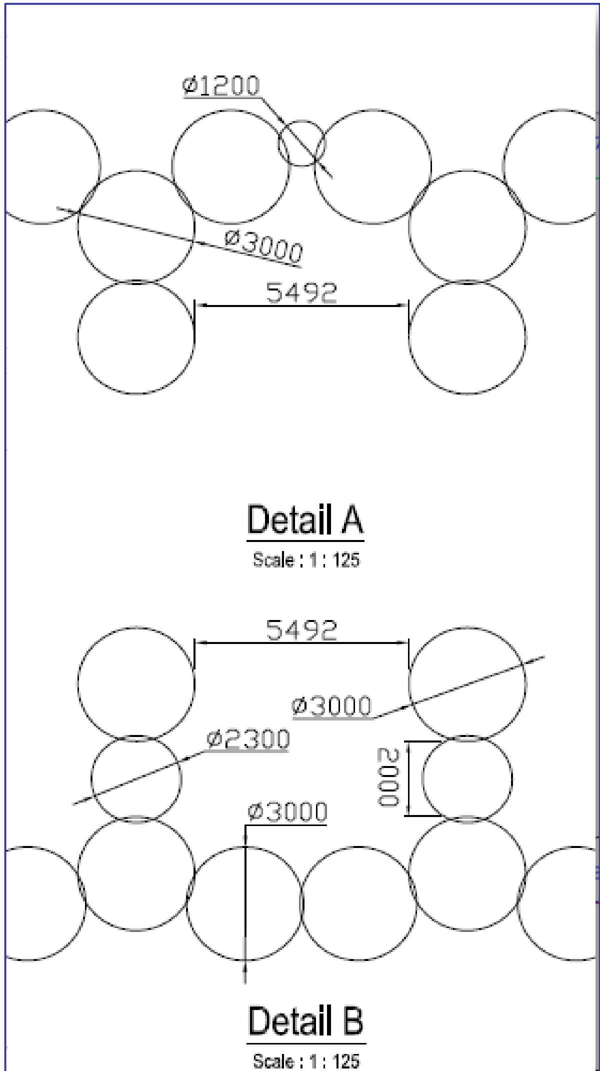

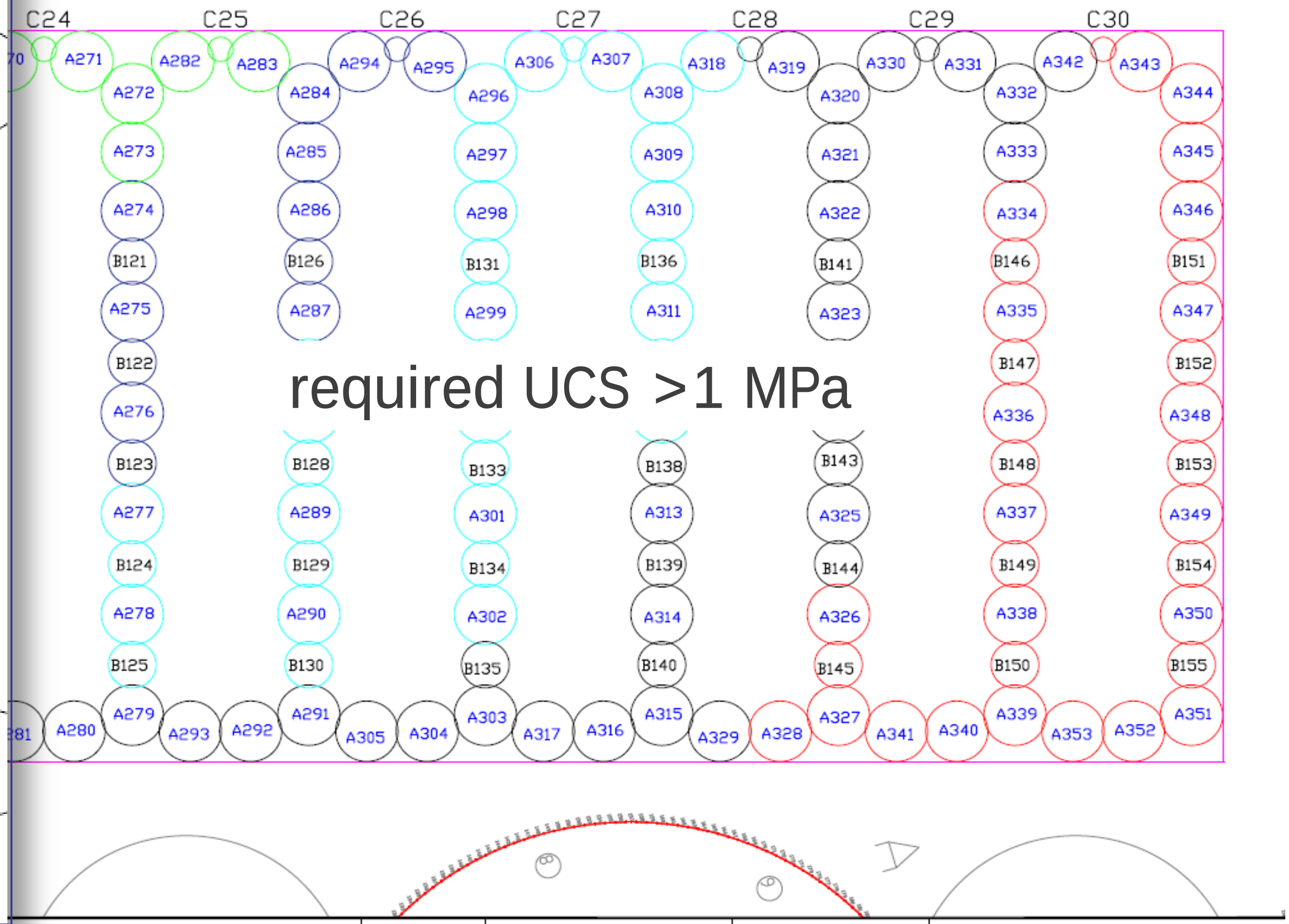

Grout production batching plant capacity up to 1200 cum/day

6 Nos. Jetting Rigs Soilmec SM-20

Improve mechanical characteristics of soft and loose soils

Improve mechanical characteristics of soft and loose soils

Improve mechanical characteristics of soft and loose soils

TREVIGroup

Improve mechanical characteristics of soft and loose soils

Improve mechanical characteristics of soft and loose soils

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QUESTIONS ?