Jet-Grouting Technology and application

TREVI Group

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TREVI soilmec Drilling and Foundation Equipment DRILLMEC DRILLING TECHNOLOGIES Petreven TREVIenergy

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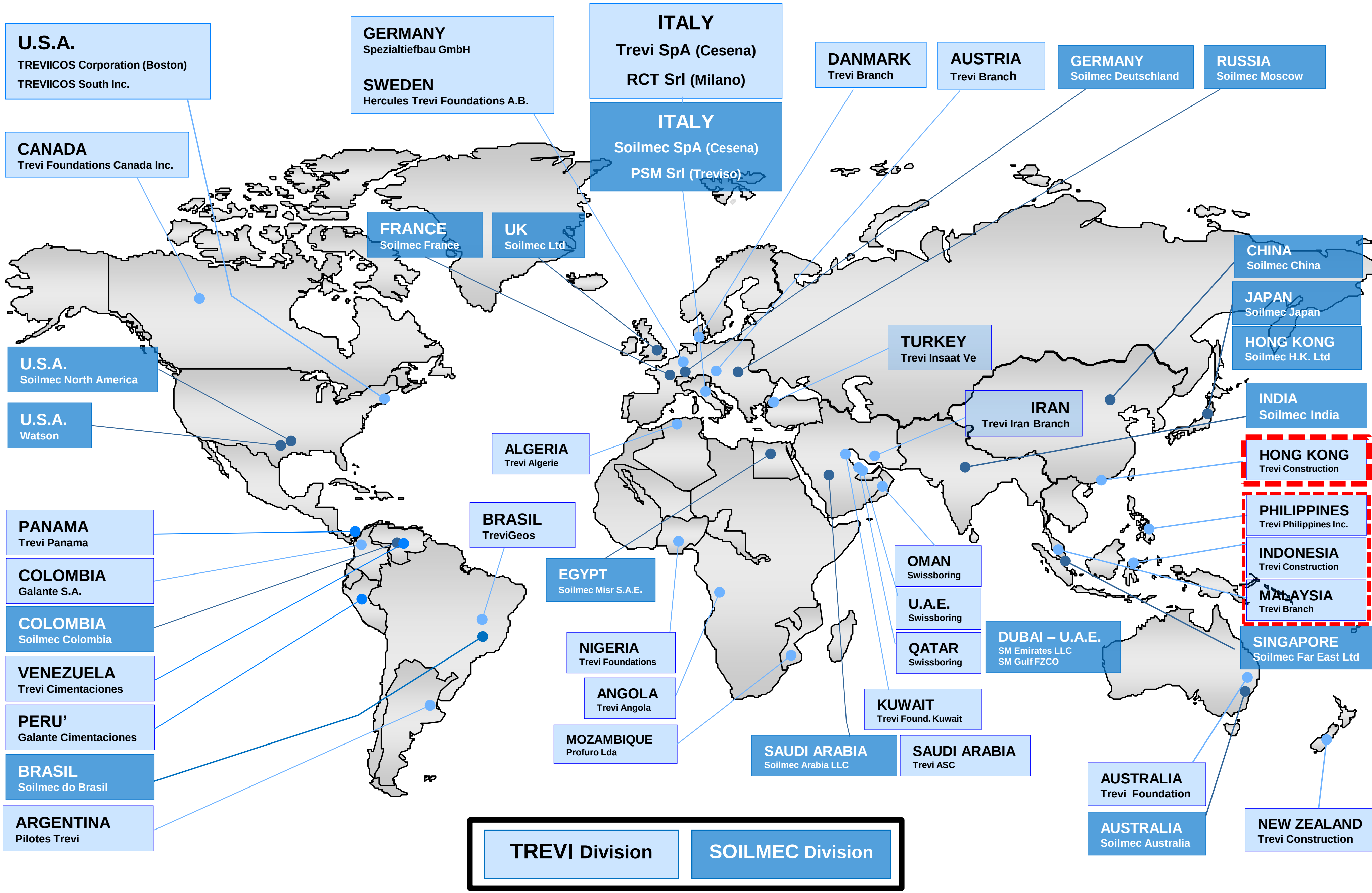
TREVIGroup

Global presence – Ground Engineering division



Classification
(one among many)

- **Soil improvement achieved by incorporation**
  - Grouting
    - Fissure G.
    - Permeation G.
    - Compaction G.
    - Cavity G.
    - Claquage G.
  - Jet Grouting
  - Deep Mixing
  - Stone Columns
  - Geotextile Encased Columns
  - Vertical Drains
    - Sand Drains
    - Prefabricated Drains
- **Soil improvement achieved by modification**
  - Dynamic Compaction
    - Impact
    - Vibration
    - Blasting
  - Drainage
    - Gravity
    - Vacuum P.
  - Thermal Treatments
    - Freezing
    - Heating
  - Electrochemical Treatments

AGENDA

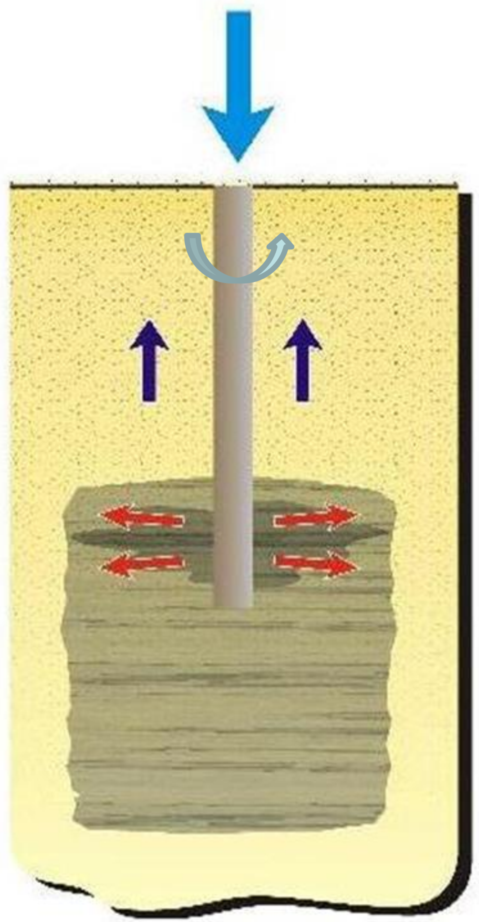
1. *GENERAL VIEW*
2. TECHNOLOGY & DESIGN
3. QUALITY CONTROLS AND MONITORING SYSTEM
4. CASE HISTORY

JET – GROUTING – General view

DEFINITION:

"The Jet-Grouting process consists of disaggregating the soil or weak rock and mixing it with, and partial replacement by, a cementing agent; the disaggregation is achieved by means of high pressure jets of fluid which can be the cementing agent itself".

(European standard EN 12716)



Applicable soils: from peaty clays to gravel

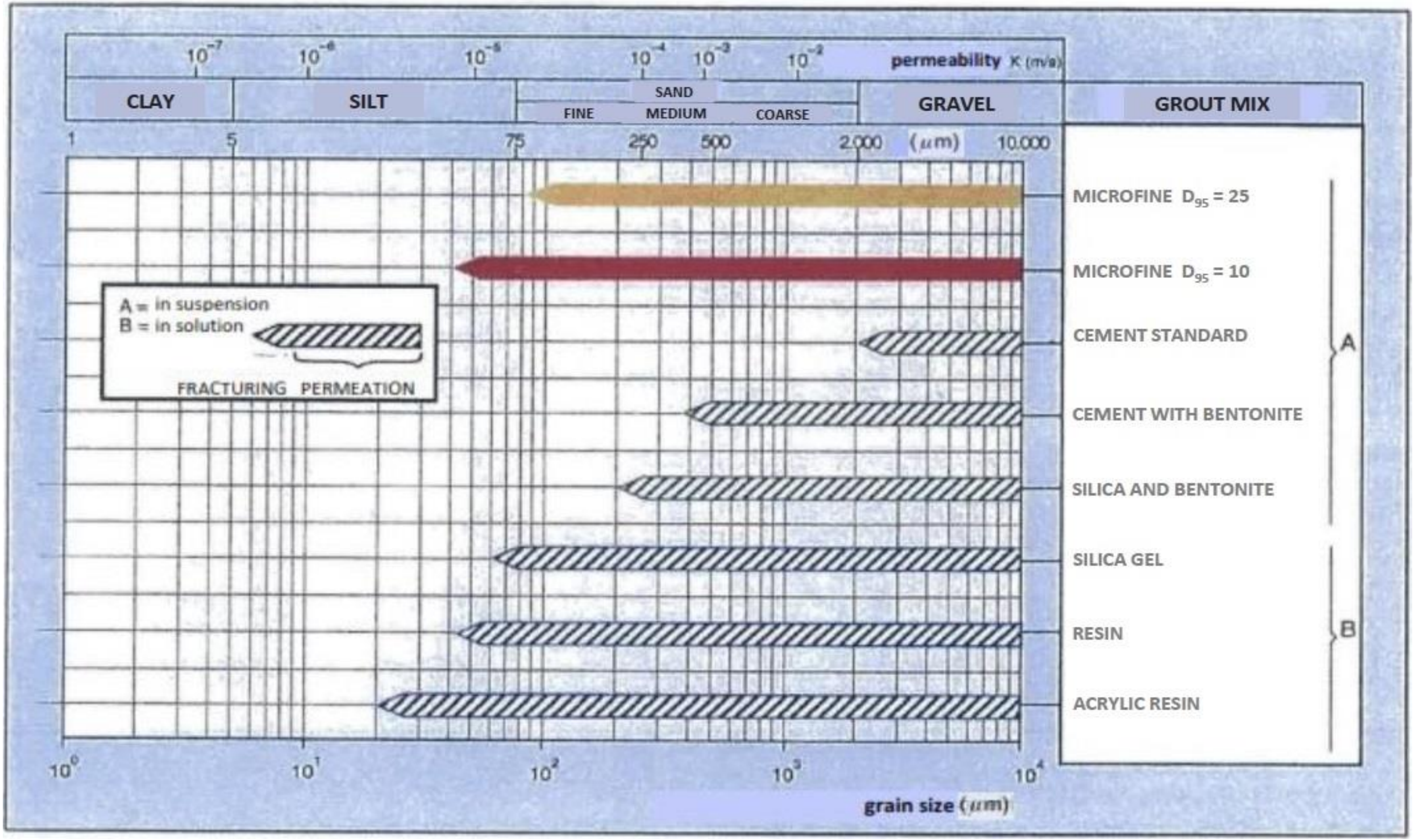
Typical geometry: approx. circular

Size: based on soil properties, injection parameters, and method used

Achievable results:
increasing strength
reducing horizontal & vertical permeability (for massive treatment)

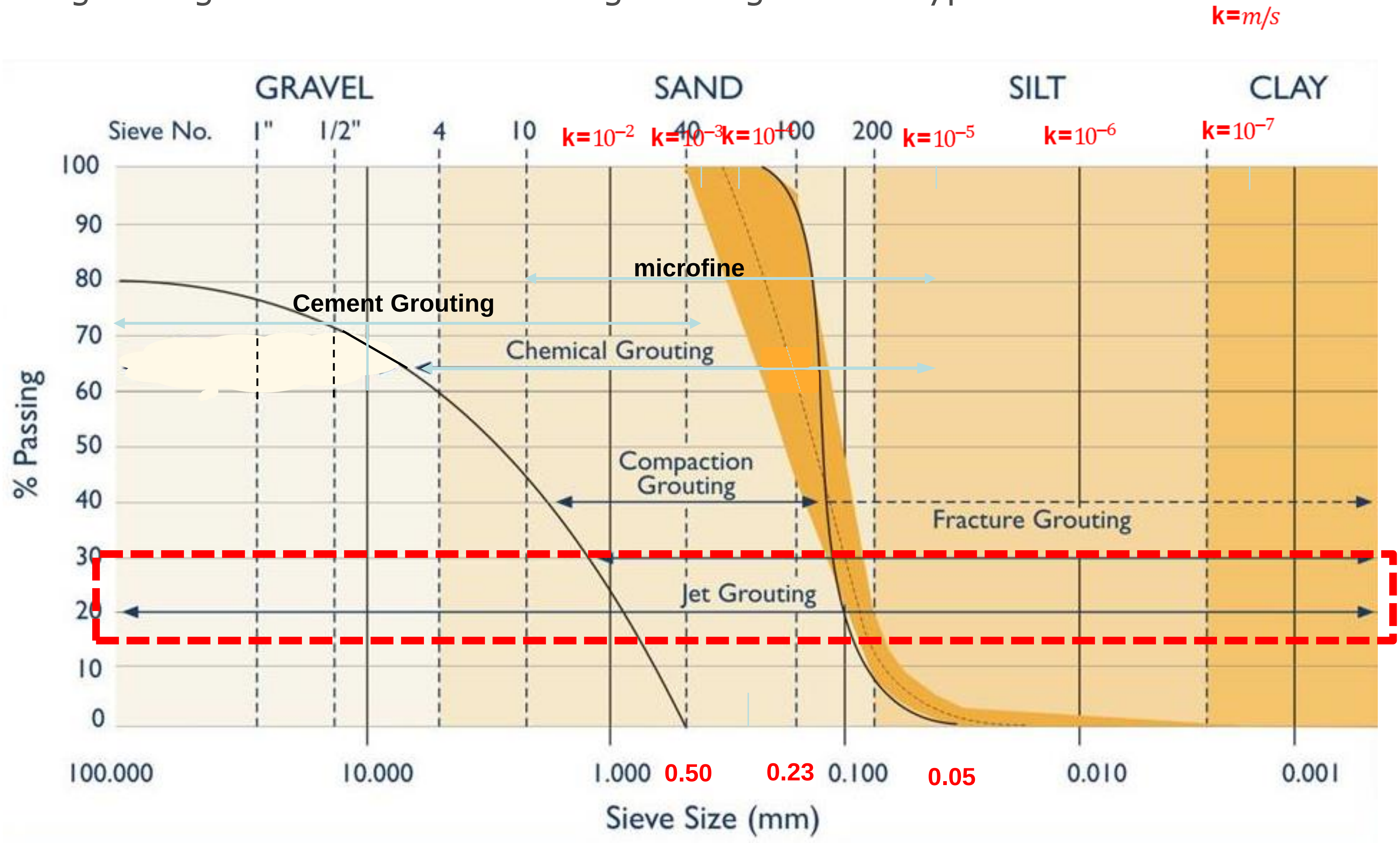
JET – GROUTING – General view

GROUTING - Mix type vs permeability & grain size



JET – GROUTING – General view

Jet grouting can be used in the largest range of soil types



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3. **QUALITY CONTROLS AND MONITORING SYSTEM**
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TECHNOLOGY AND DESIGN

Selection of methods and technologies for soil improvement depends on the following factors:

- nature and original characteristics of the soil;
- general target of the treatment (i.e. higher strength? lower permeability? both?);
- final requirements of the treated soil (i.e. depth, UCS value, permeability value etc.);
- site logistics and surrounding conditions (i.e. presence of buildings in the surroundings, low headroom conditions, restricted and/or limited working space etc.).
- Equipment and personnel ability

Grouting

For all ECS (European Committee for Standardization) member countries(*), the reference standard for the execution of GROUTING WORKS is the European Standard:

EN 12715:2000

"Execution of special geotechnical works – Grouting"

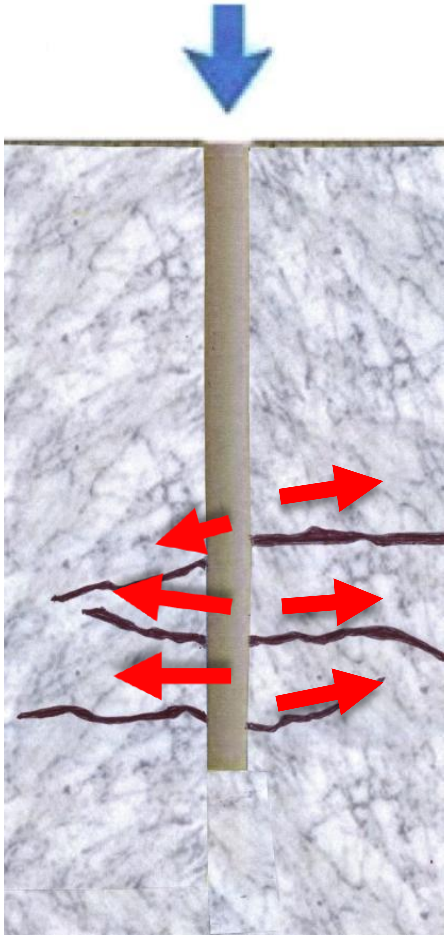
prepared by the Technical Committee CEN/TC 288.

The standard applies *"to the execution, testing and monitoring of geotechnical grouting works"*.

(*) *Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom*

Fissure Grouting

"... pressure injection of a cement based or chemical grout into rock fissures, joints, fractures and discontinuities".



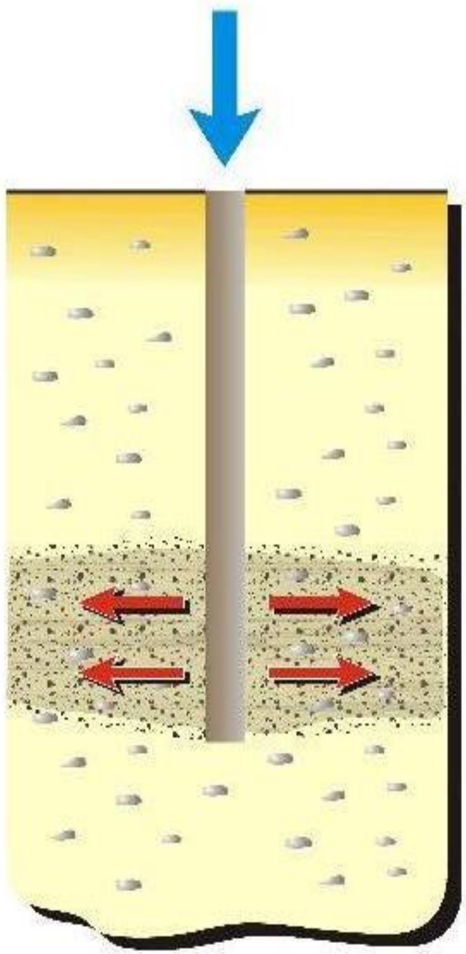
Applicable soils: fissured and fractured rocks

Achievable results:
- increasing strength
- reducing horizontal & vertical permeability

Limits:
- experienced personnel
- quite expensive plants
- quite expensive QC systems
- high costs of materials when dealing with fine fissures

Permeation Grouting

"... replacement of interstitial water or gas of a porous medium with a cement based or chemical grout at injection pressures low enough to prevent displacement".



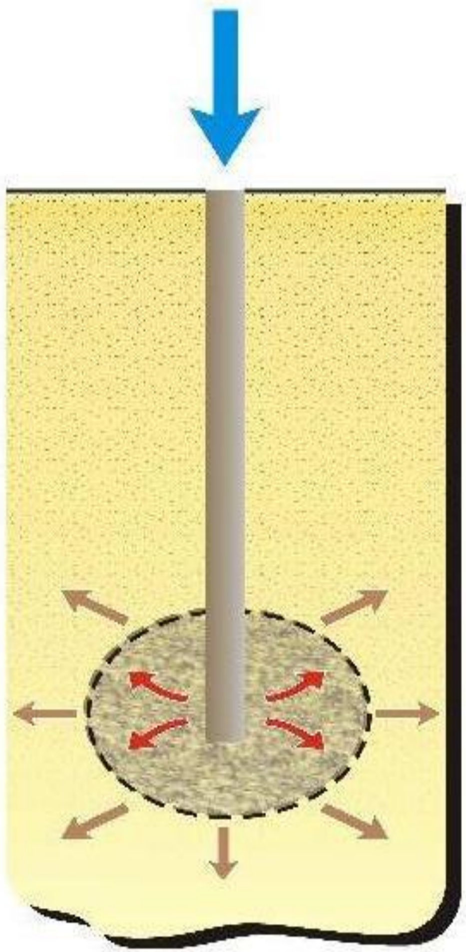
Applicable soils: silty sands to gravel

Achievable results:
- increasing strength
- reducing horizontal & vertical permeability

Limits:
- experienced personnel
- quite expensive plants
- quite expensive QC systems
- high costs of materials when dealing with fine fissures

Compaction Grouting

"... pressure injection of a mortar of high internal friction (i.e. low mobility) into the soil to compact it without fracturing".



Applicable soils: loose to medium dense sands

Achievable results:

- increased load bearing capacity by densification
- mitigation of liquefaction risks
- controlled up-heave at surface

Limits:

- risk of excessive heaves
- quite experienced personnel

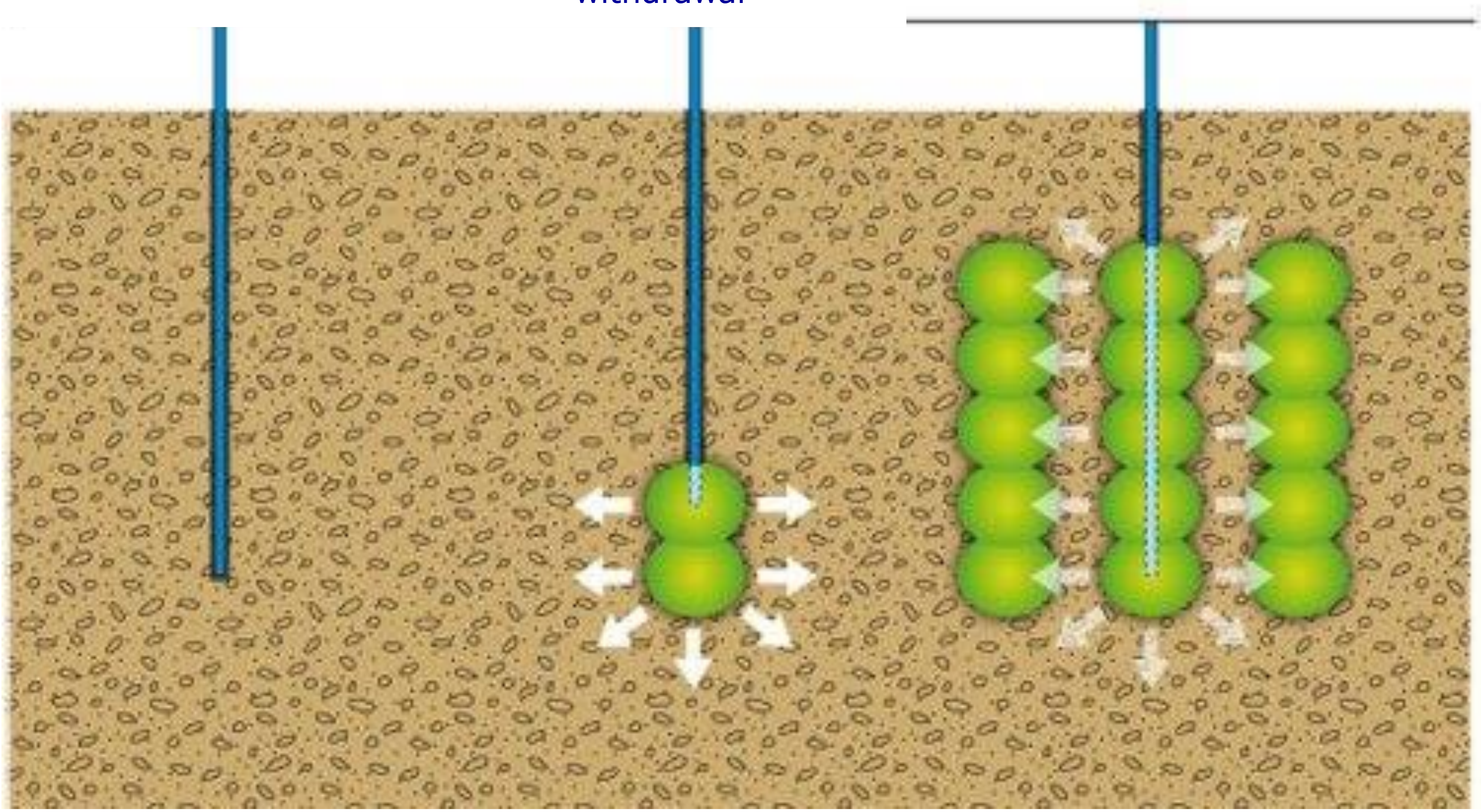
Compaction Grouting

Drilling & Grouting Sequence

Cased rotary drilling

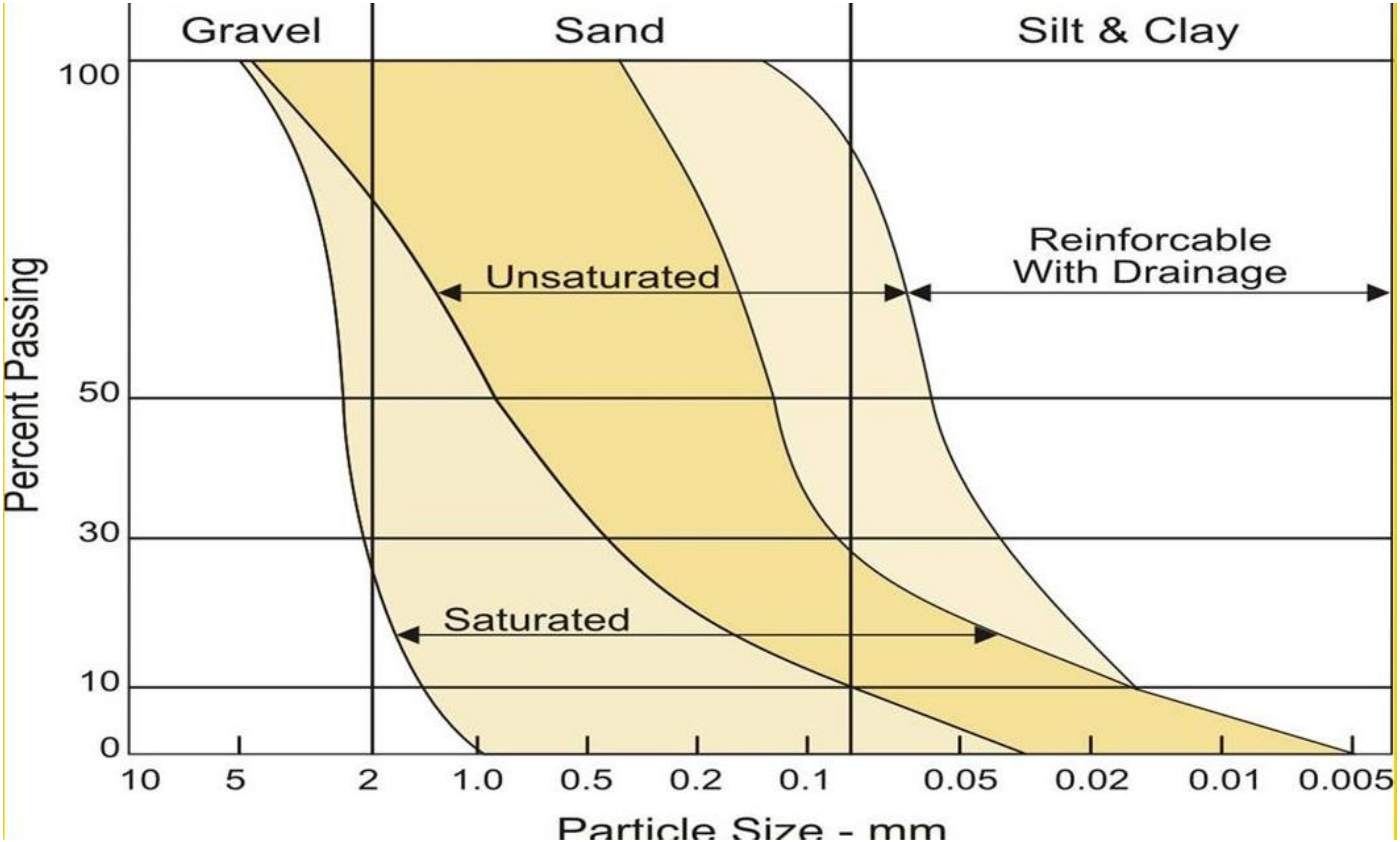
Mortar injection with intermitted casing withdrawal

The operation is repeated until the designed top level is reached



Compaction Grouting

Range of suitable soils



Cavity Grouting

".. filling by gravity or low pressure of substantial voids by a thick grout or a mortar".

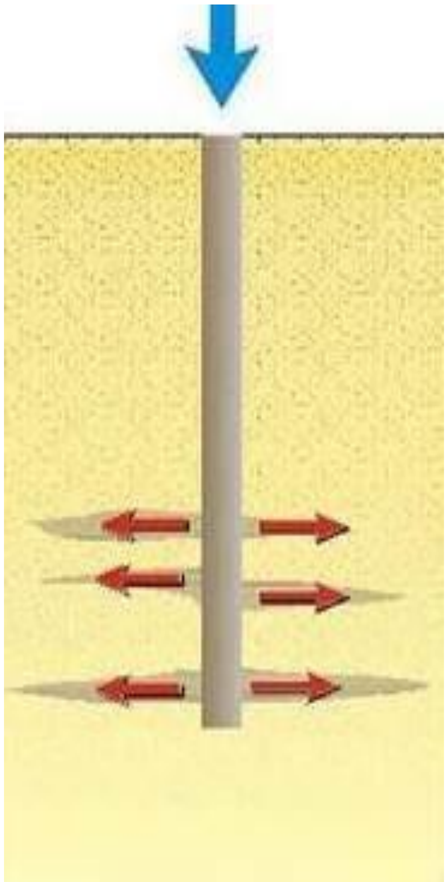
Applicable soils: any soil formation subject to the formation of voids (i.e. karstic features) or sinkholes

Achievable results:
- increase load bearing capacity by voids filling
- reduce overall permeability

Limits: no remarkable

Claquage Grouting

".. fracturing of a ground by the injection of a thick grout mix under a pressure in excess of local tensile strength and confining pressure".



Applicable soils: dense sandy formations
stiff cohesive formations
very soft rock (shale etc.)

Achievable results:

- increased load bearing capacity by compressing the soil between the grout lenses
- reduced vertical permeability

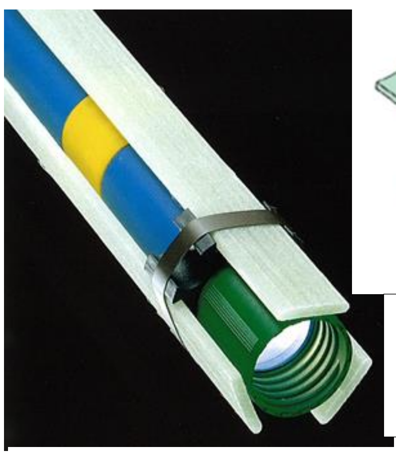
Limits:

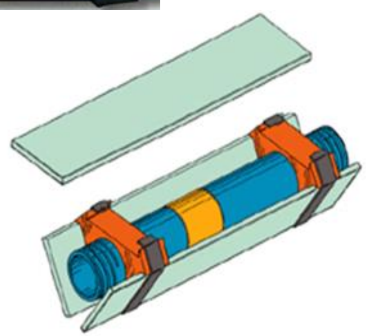
- risk of heaves at the surface
- experienced personnel
- extensive instrumentation
- no influence on horizontal permeability

Permeation Grouting

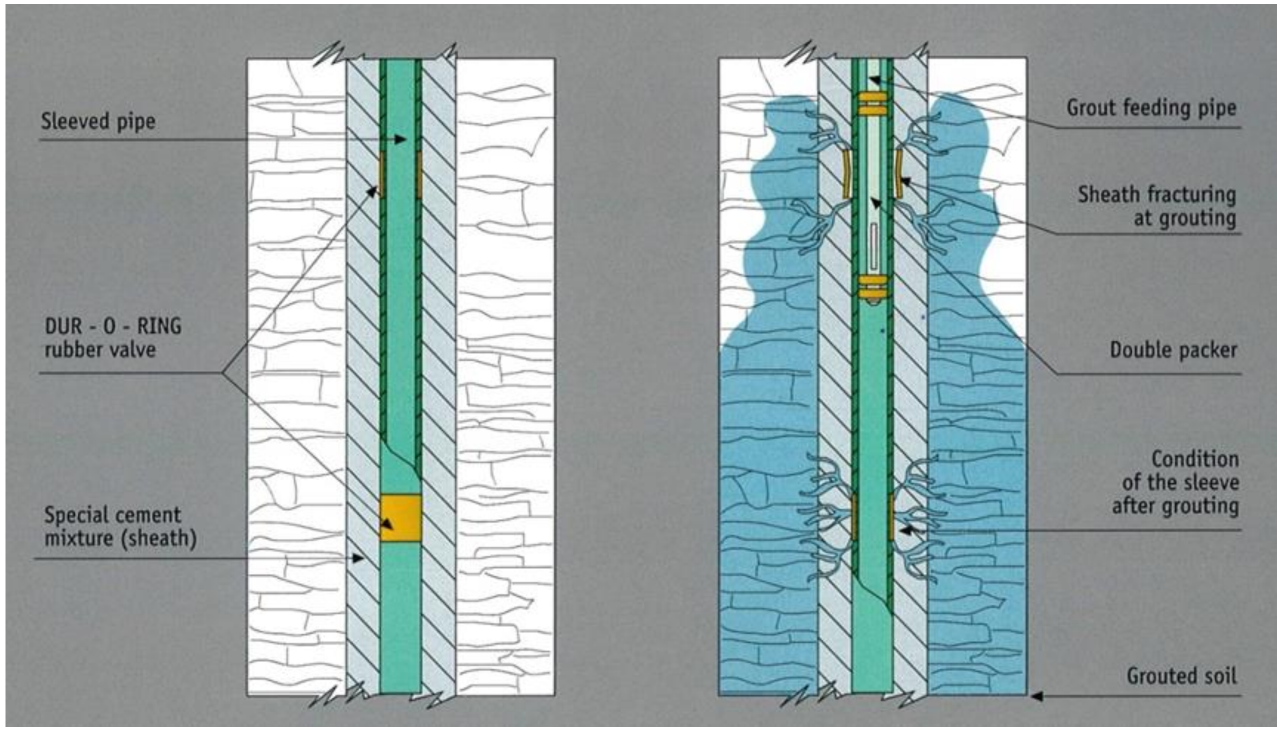
The no-return sleeved pipe (“*tube à manchettes*” or TAM)

traditional PVC sleeved pipes





PVC sleeved pipes reinforced with fiberglass plates



double packers for TAM grouting

Permeation Grouting

TREVI foundation specialists

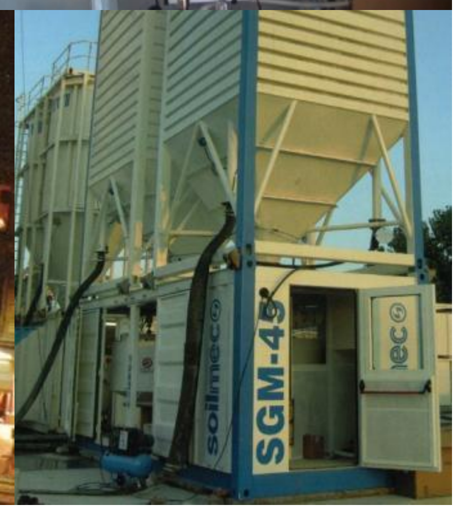
Drilling Equipment

Permeation Grouting

TREVI foundation specialists

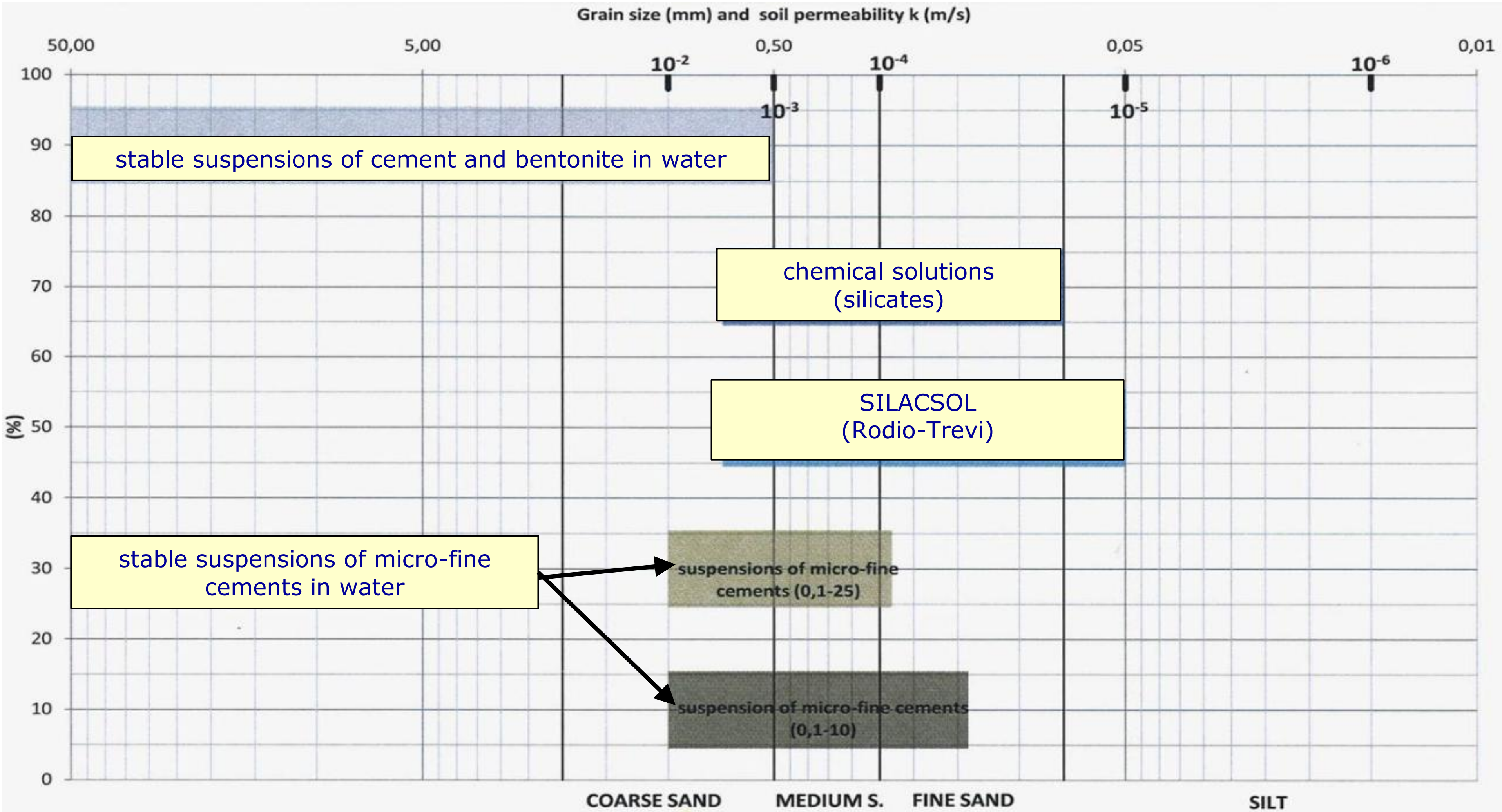
Grouting Equipment



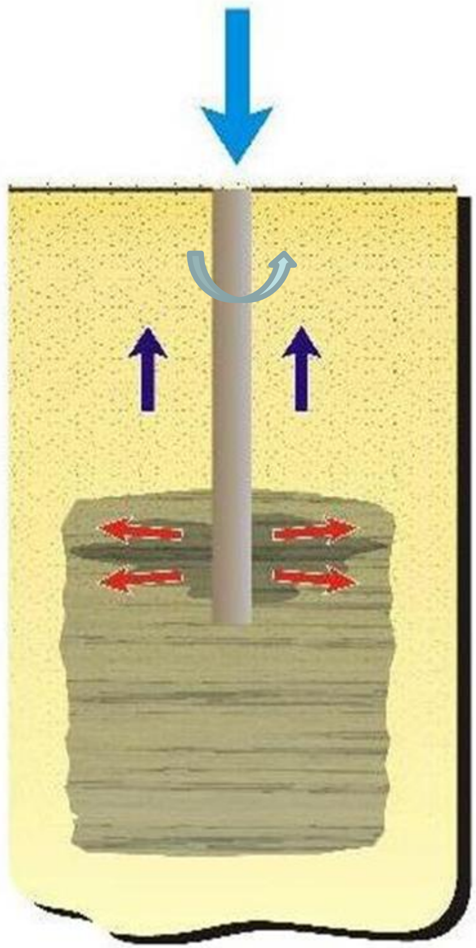
Permeation Grouting

Grout Mixes



Jet Grouting

"... disaggregation of the soil and its mixing in place with, and partial replacement by, a cement grout mix; the disaggregation is achieved by high energy jet of one or more fluids, one of them being the grout mix itself".



Applicable soils: from peaty clays to gravel

Achievable results: increasing strength
reducing horizontal & vertical permeability (for massive treat-ment)

Limits:
risk of excessive heaves at the surface
experienced personnel
strict safety rules
expensive equipment
large quantity of spoil to be managed

Jet Grouting

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EN 12716:2001

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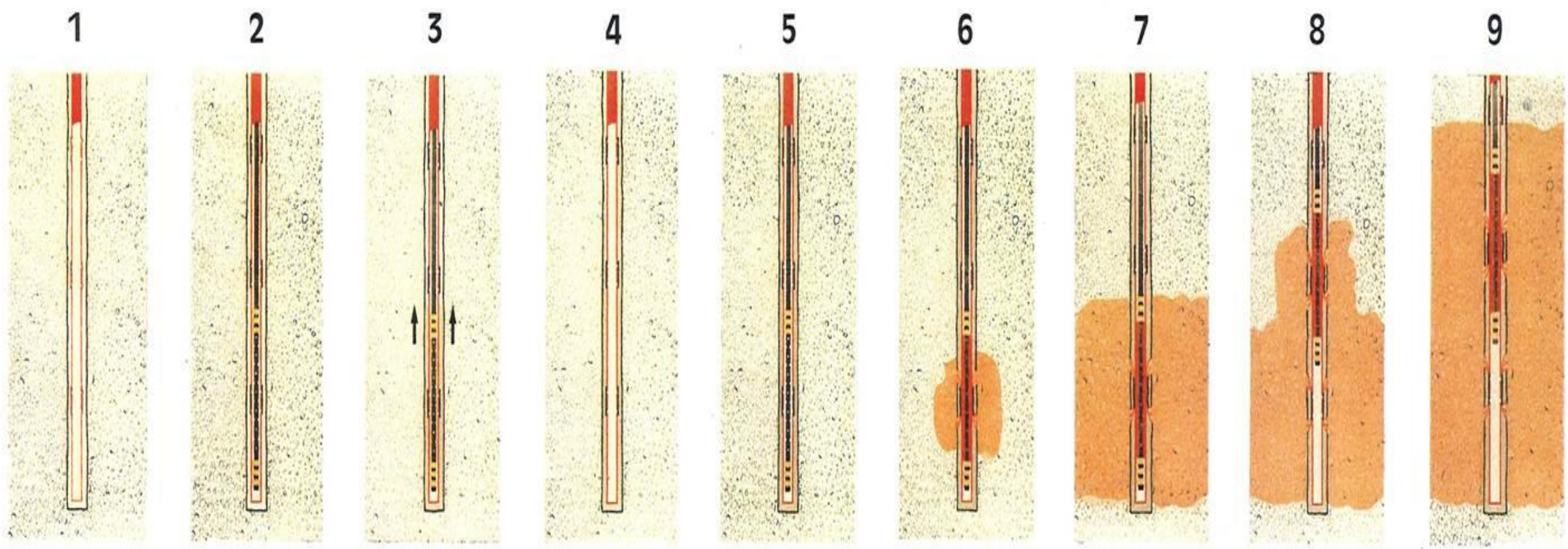
The standard applies "*to the execution, testing and monitoring of jet grouting works*".

(*) *Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom*

Permeation Grouting

TAM Grouting Method



1 - sleeved pipe for grouting

2 - double packer set at the lowermost valve for the forming of sheath

3 - forming of sheath in the annular space between the pipe and the soil

4 - sheath completed

5 - double packer set at the lowermost valve for the up-stage grouting of soil

6 - breaking-out of the sheath through the lowermost valve

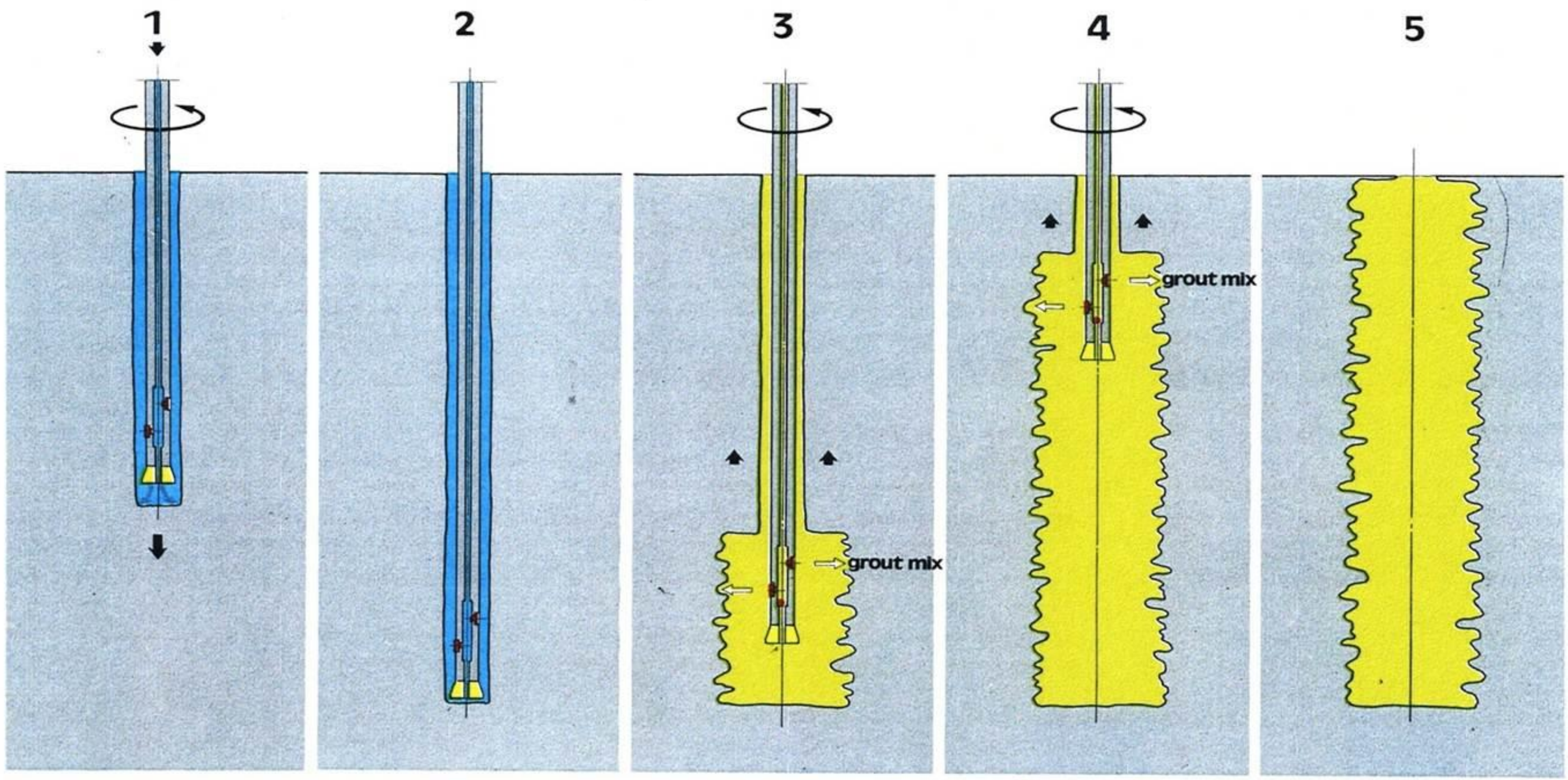
7 - soil grouting through the lowermost valve completed

8 - breaking-out of the sheath through the 2nd lowermost valve

9 - soil grouting through the 1st and 2nd lowermost valves completed

Jet Grouting

Drilling & Jetting Sequence



1 drilling

2 drilling completed

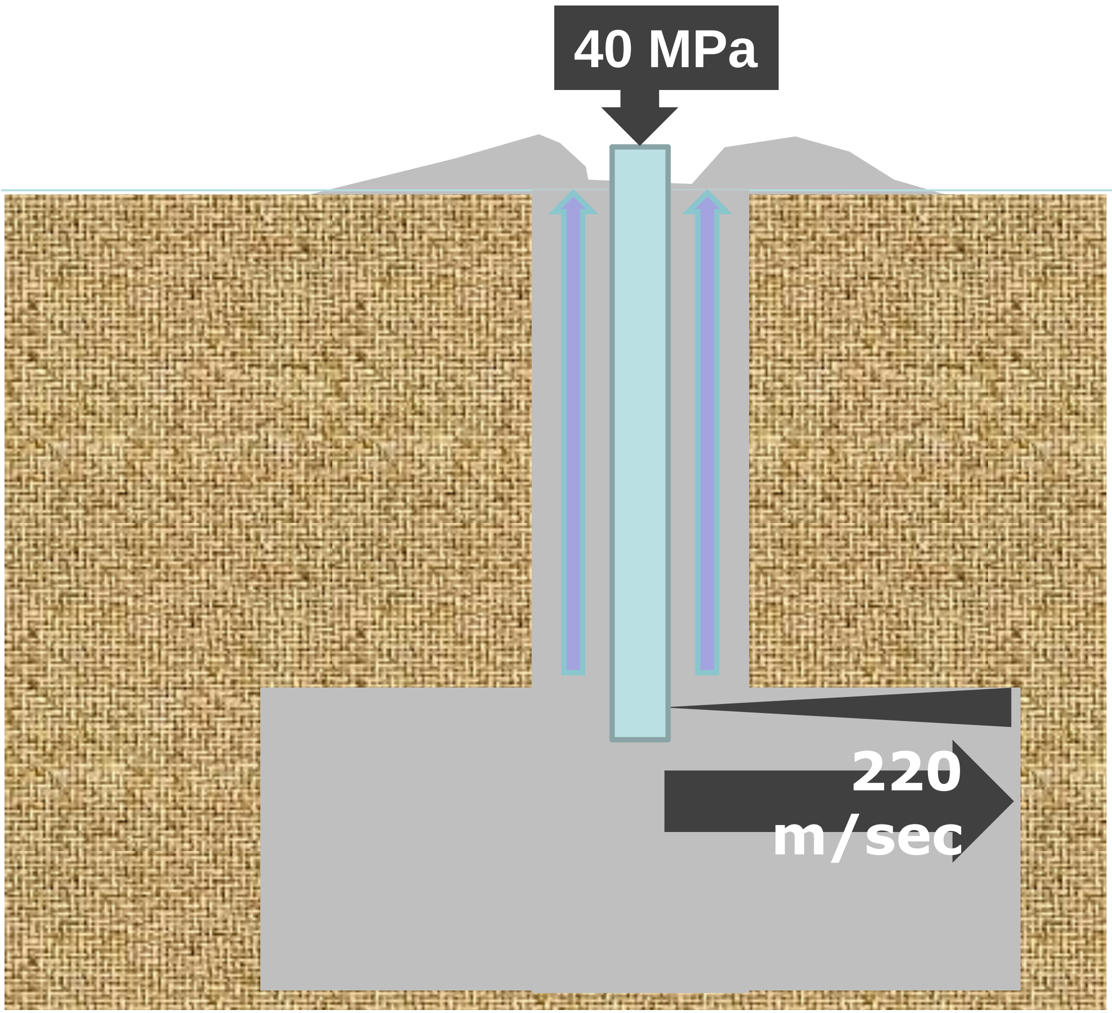
3 commencement of jet-grouting

4 rotary drill rod extraction while jet-grouting

5 completed grouted soil column

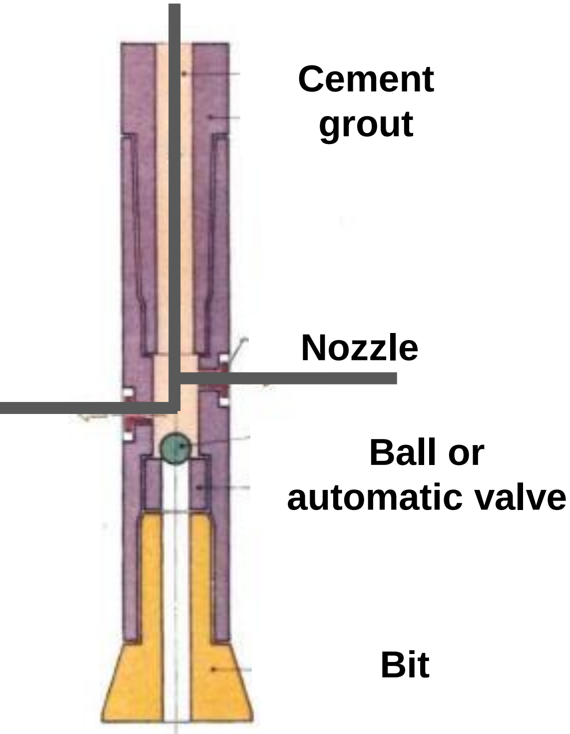
Jet Grouting
Spoil

Pressure → kinetic energy



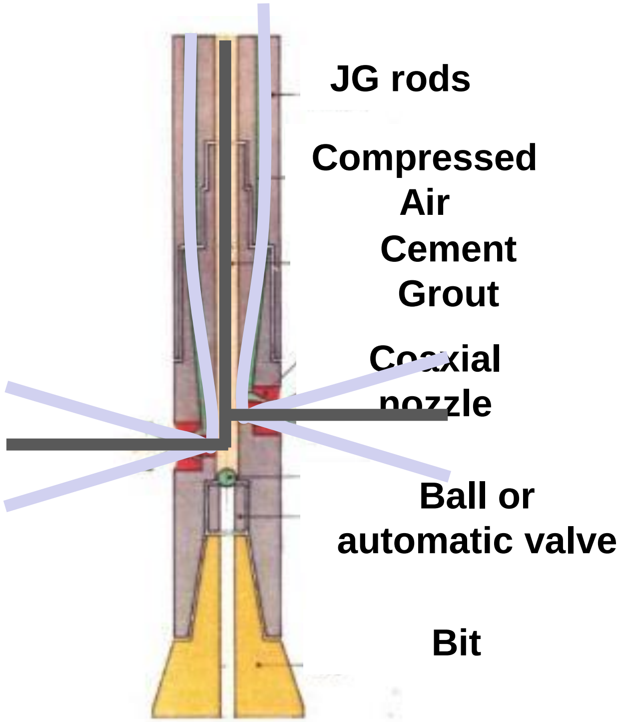
Spoil return shall be maintained at all times, to avoid hydrofracturing of soil

Jet Grouting classification according to the number of injected fluids.



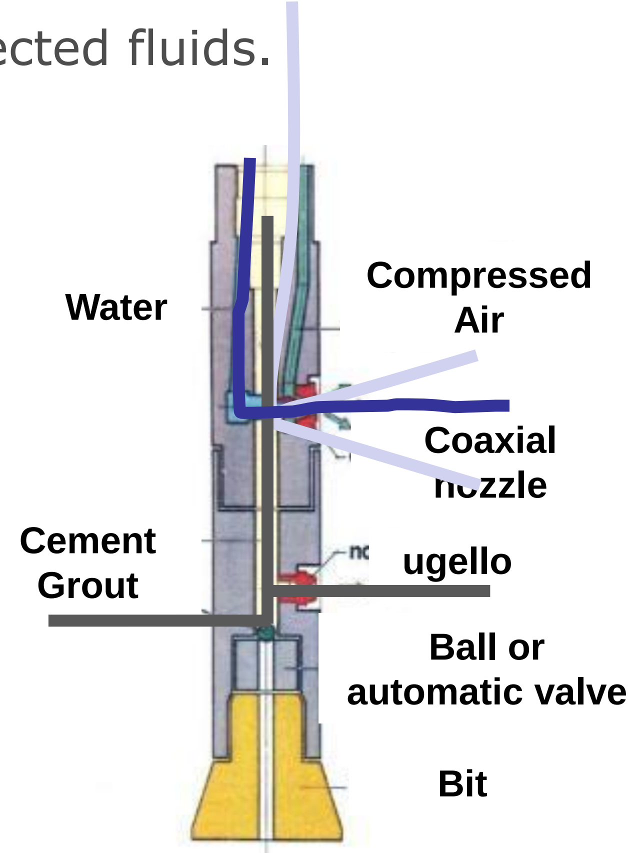
"Monofluid"

The break-up and the consolidating actions are carried out at the same time and are accomplished through injection of a single fluid (i.e. a cement mixture).



"Double-fluid"

The break-up and the consolidating actions are carried out at the same time and are accomplished through injection of a cement mixture surrounded by an air flow.



"Three-fluid"

The break-up action is carried out through injection of water surrounded by an air flow, while the consolidating action is achieved through injection of a cement mixture.

Jet Grouting

Typical jetting parameters

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

Jet Grouting

A simplified comparison between the three systems

Characteristic	*"single fluid"*	*"double fluid"*	*"triple fluid"*
Column's diameter	★	★★★	★★★
Increase in strength	★★★	★	★★
Reduction in permeability	★★★	★★	★★★
Original soil replacement %	★	★★	★★★
Quantity of spoil rising to the surface	★	★★	★★★
Cost of the equipment	★	★★	★★★
Risk of heaves at the surface	★★★	★★	★
Productivity	★	★★★	★★★
Sub-horizontal execution	Only one applicable	Not applicable	Not applicable

★ lower ★★ intermediate ★★★ higher

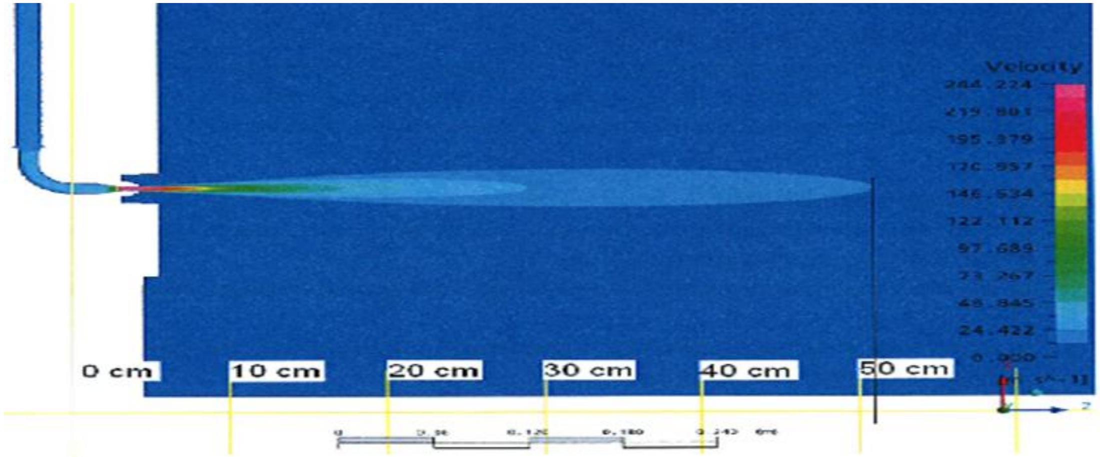
Single Fluid Spoil

Double Fluid Spoil

HIGH-EFFICIENCY JET GROUTING (ETJ)

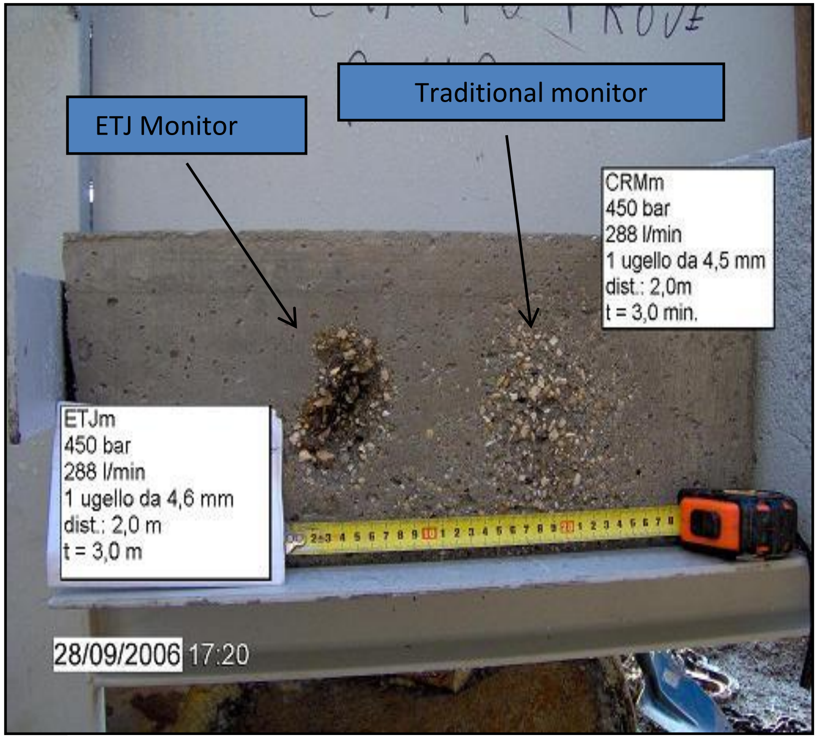
During the last years, the Trevi Group has been carrying out theoretical and experimental studies devoted to improve the effectiveness of the disgregating and/or consolidating jet.

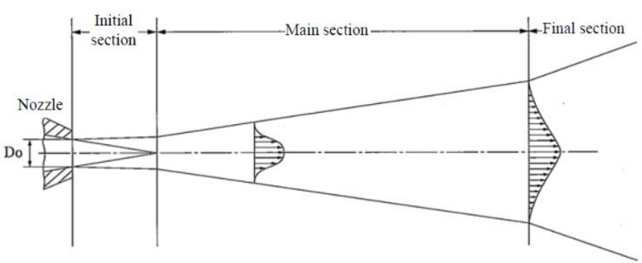
Said studies have found out that <u>the geometric shape of the fluid’s conducts next to the outlet nozzles highly affects the jet’s “disintegrating” capability.</u>



HIGH-EFFICIENCY JET GROUTING (ETJ)

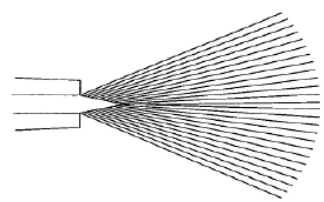
A new-concept and high-efficiency monitor, called ETJ (Enhanced Trevi Jet), as well as nozzles shape, allows the flow of the disintegrating and/or consolidating mixture to be more concentrated and effective compared to traditional ones.





TRADITIONAL monitor

ETJ monitor



(B)

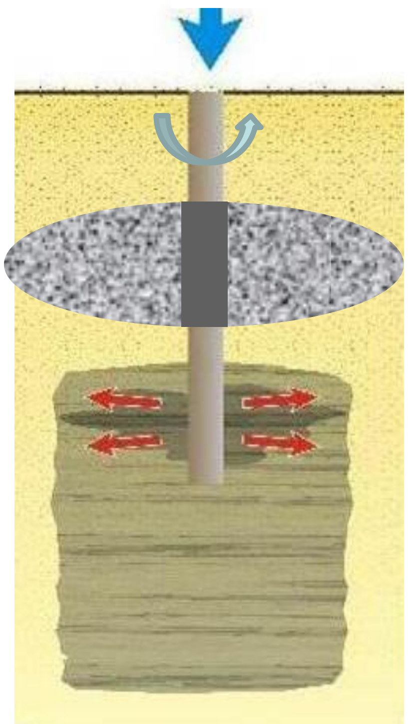
(A)

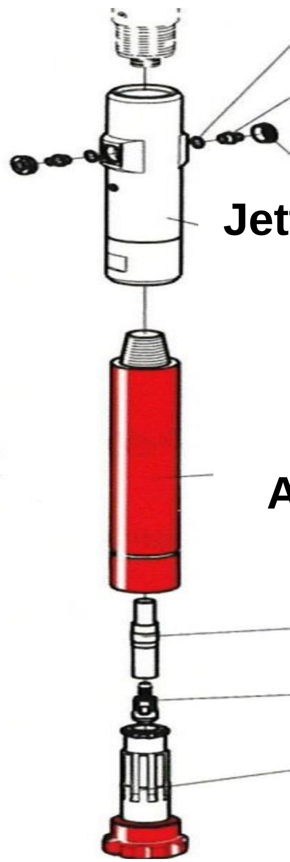
Jet Grouting

TREVI foundation specialists

The reasons for its worldwide success

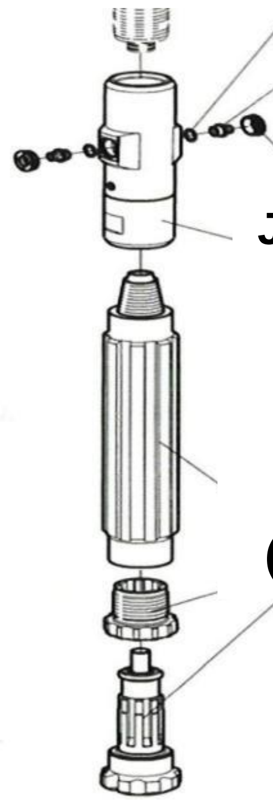
By using the most appropriate drilling technology, it’s possible to pass through natural (i.e. boulders, rocky formations etc.) or man-made (i.e. old masonry or concrete foundations etc.) obstacles.





Jetting monitor

Air-driven DTHH



Jetting monitor

Water-driven DTHH (WASSARA®)

Jet Grouting

Equipment

Hydraulic drilling rig with automatic drilling/grouting parameters recorder

Automatic high capacity (20 ÷ 25 m³/h) grout batching and mixing plant

High pressure (40 ÷ 60 MPa) grout pump, 400 to 1000 HP

“single fluid”

+

High capacity (20 m³/min at 2 MPa) air compressor

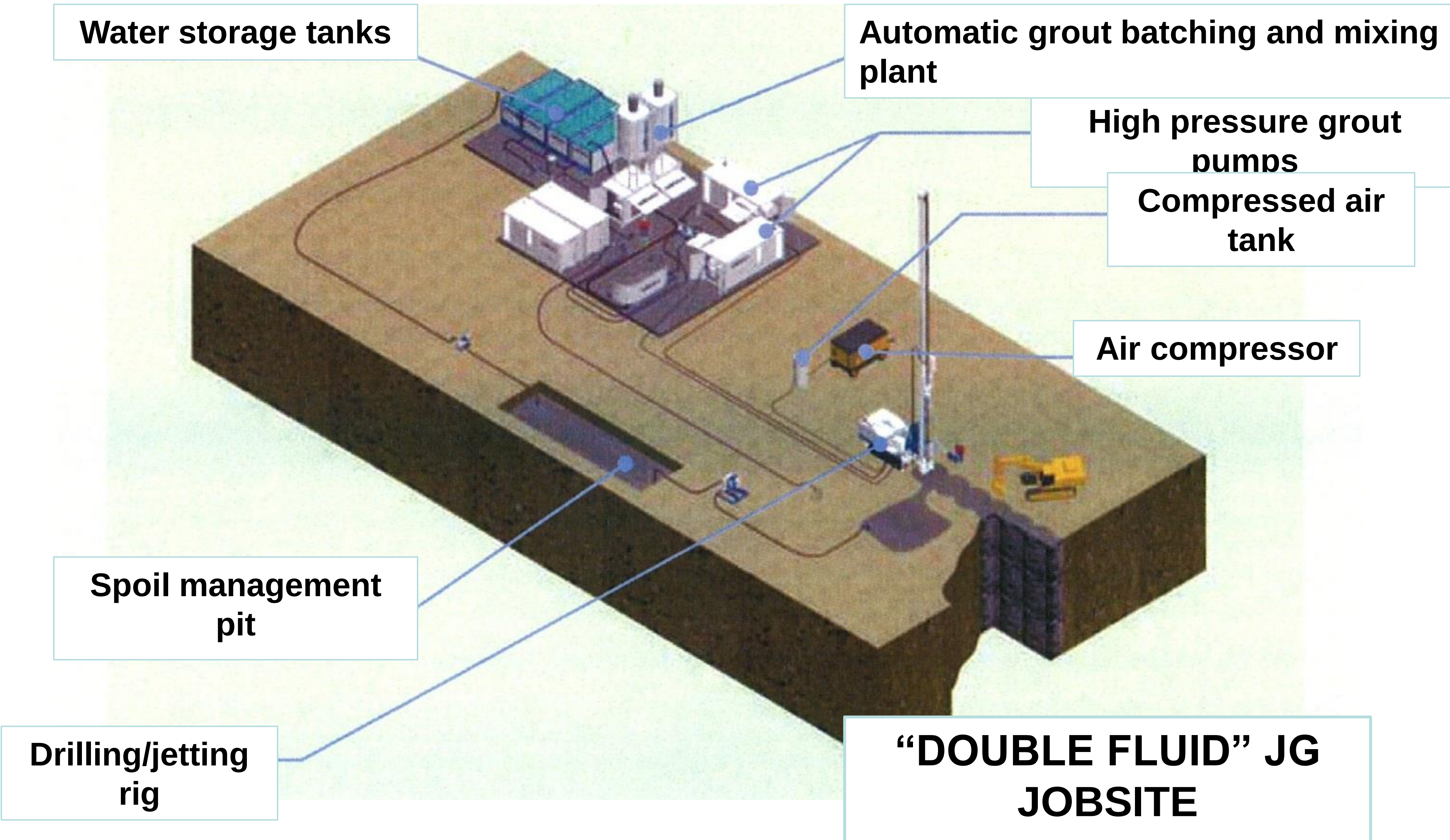
“double fluid"

+

Medium pressure (20 ÷ 30 MPa) grout pump

“triple fluid"

Jet Grouting

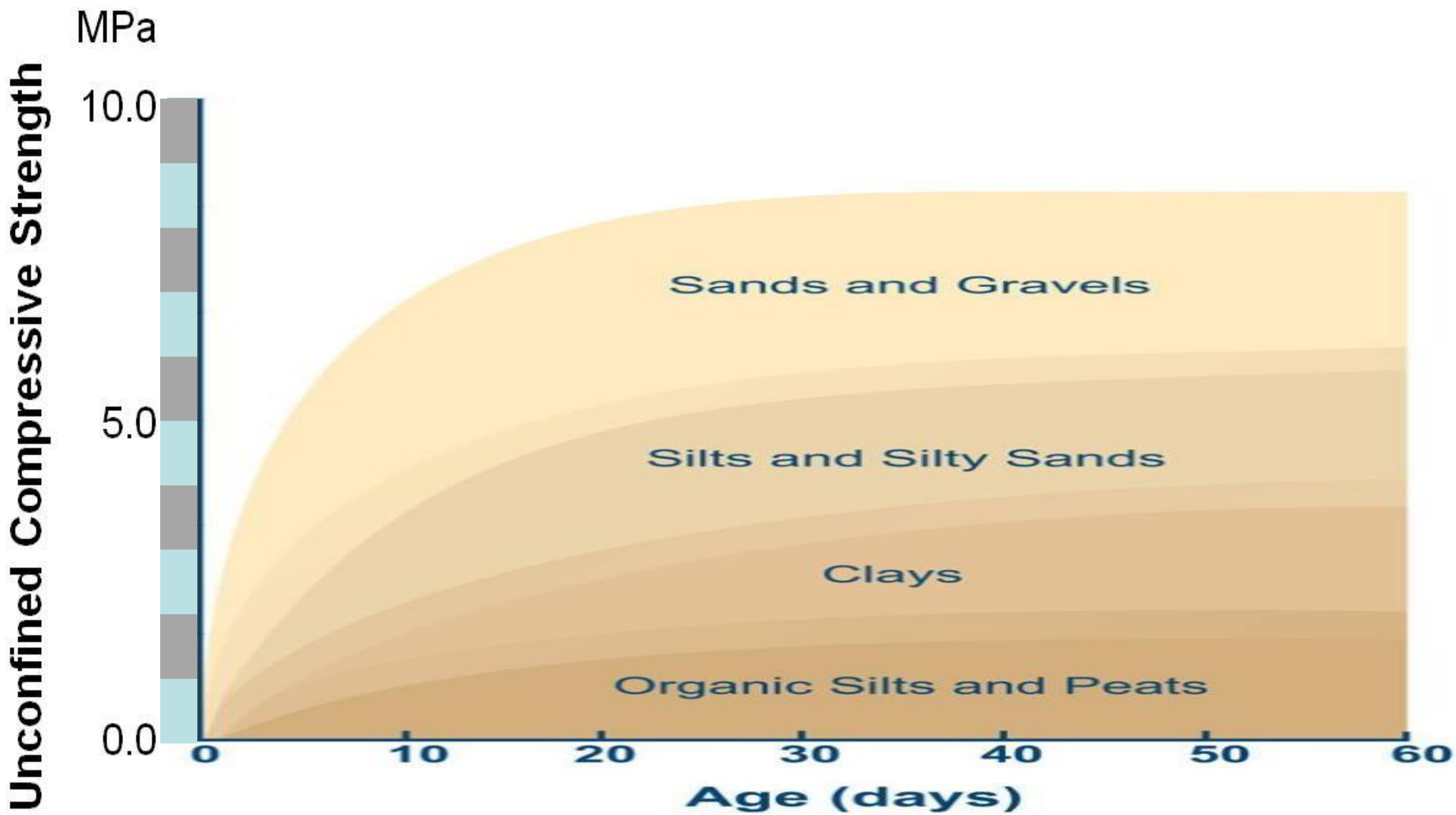


RECENT DEVELOPMENTS

- Soil erodibility plays a major role in determining geometry, quality and production.
- Cohesionless soils are typically more erodible than cohesive soils.

Design aspects
Typical Jet Grouting Strengths

- Strengths are variable and difficult to predict, particularly in layered soils.
- Strength increases (slowly) with age
- Organic content can decrease final strength



Design aspects
Specific Energy Approach

Specific Energy $E_S = P \times Q/V_t$ (MJ/m)

where:

- P = fluid(s) pressure (MPa)
- Q = fluid(s) flow rate (m^3/h)
- V_t = rods withdrawal speed (m/h)

$$E_g = \frac{P_g \times Q_g}{V_t}$$

$$E_w = \frac{P_w \times Q_w}{V_t}$$

$$E_a = \frac{0{,}35 \times Q_a \times [(10 \times P_a)^{0{,}29} - 1]}{V_t}$$

E_g = Grout jet specific energy
E_w = Water jet specific energy
E_a = Air jet specific energy
E_t = Total specific energy

Jet Methods	Eg MJ/m	Ew MJ/m	Ea MJ/m	Et MJ/m
Single Fluid	10 ÷ 20	-	-	10 ÷ 20
Double Fluid	20 ÷ 40	-	10 ÷ 20	30 ÷ 60
Triple Fluid	5 ÷ 20	30 ÷ 120	20 ÷ 70	50 ÷ 200

Jet Grouting

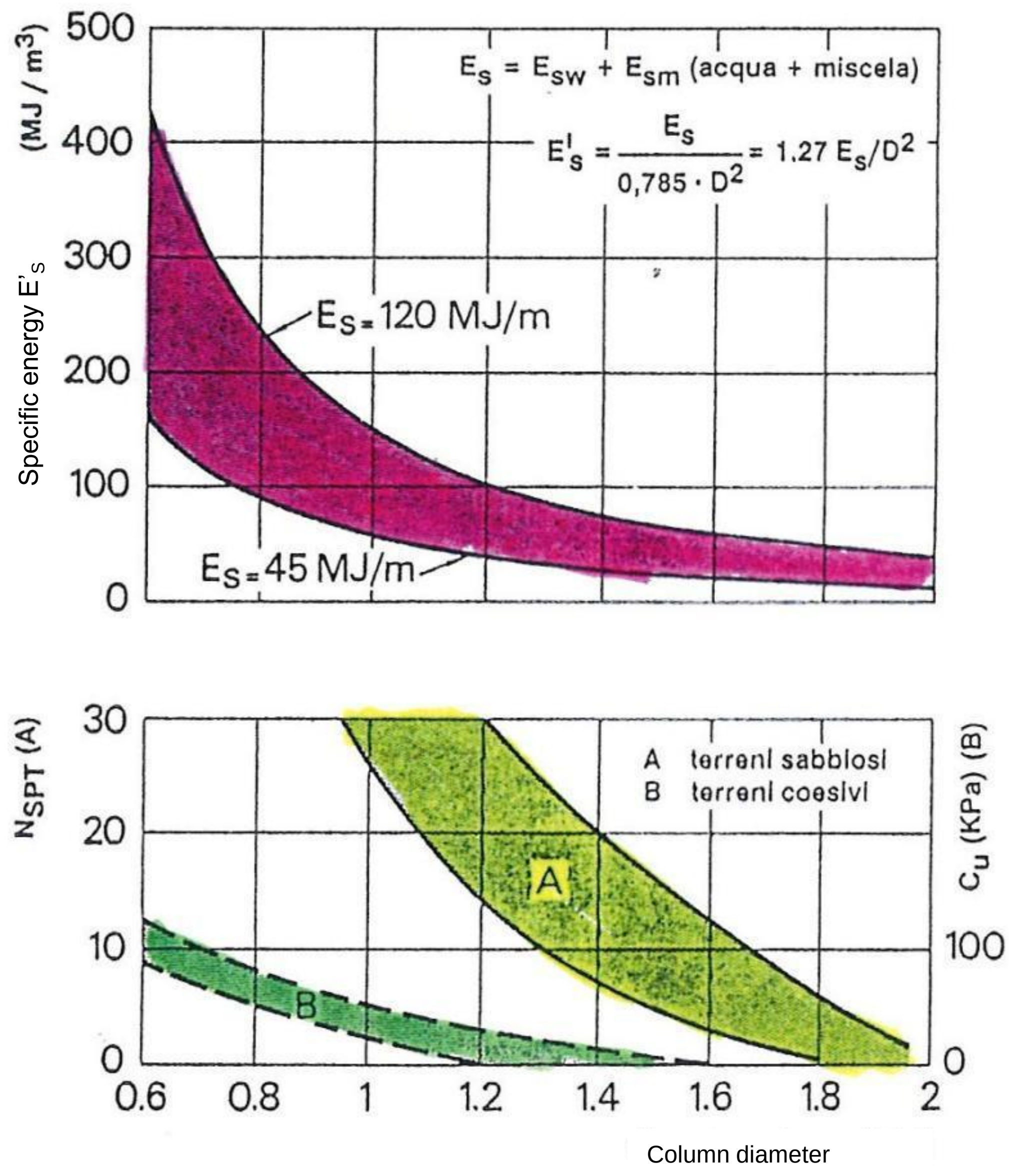
TREVI foundation specialists

Design aspects

Energy and Diameter

The diameter of the column can be correlated to the specific energy per linear meter (E_s in MJ/m) or per cubic meter of treated soil (E'_s in MJ/m^3).

TRIPLE FLUID

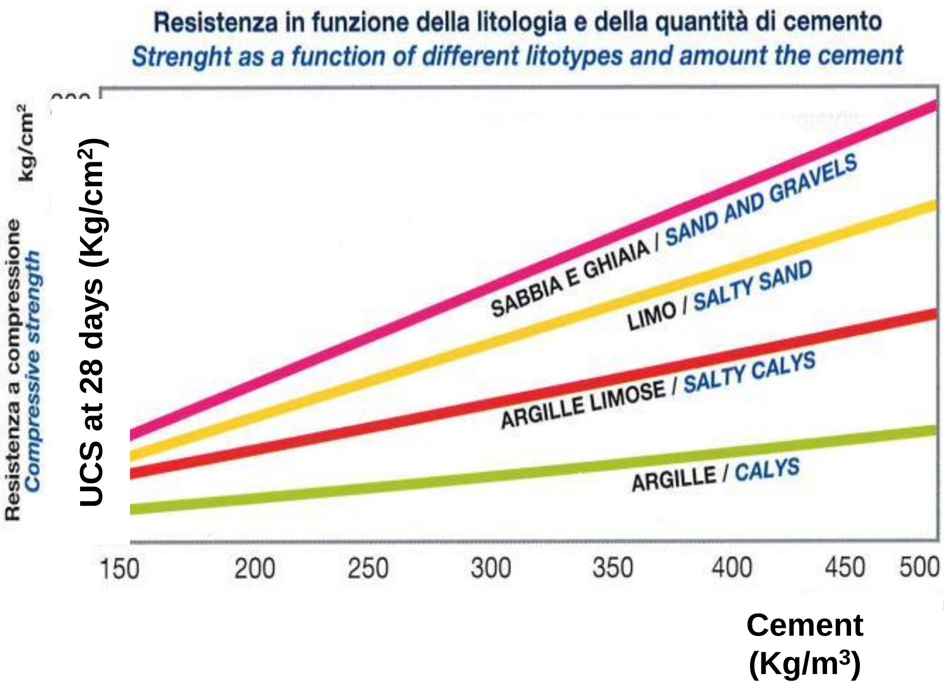


Jet Grouting

Geomechanical characteristics of the treated soils

Final result of JG process = water + cement + original soil

→final strength of treated soil = influenced by original soil + quantity of cement

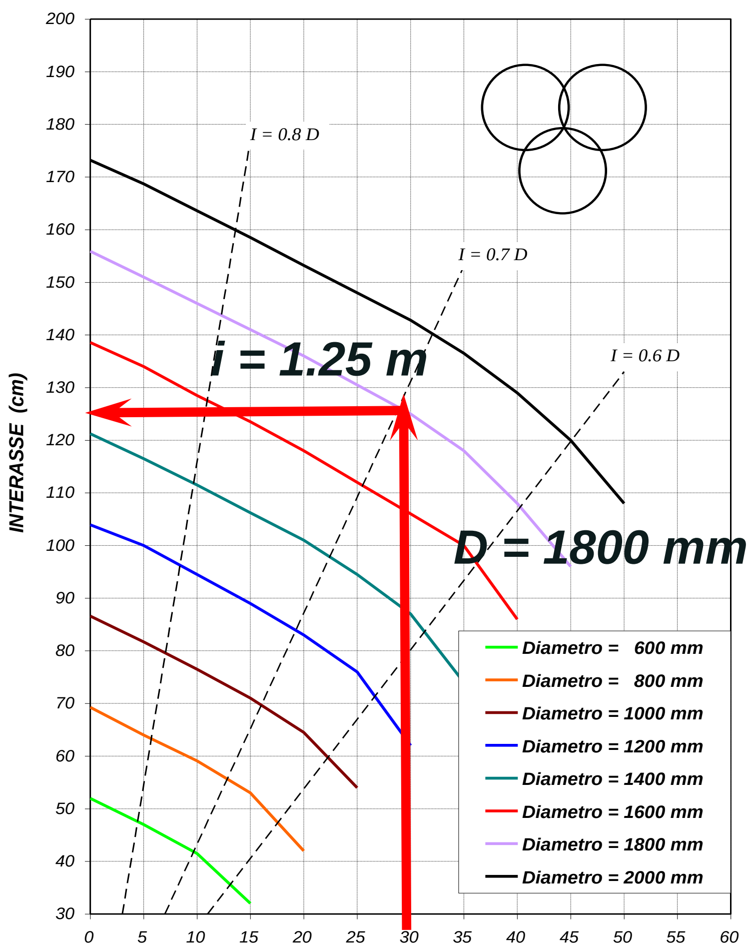


PREVAILING SOIL	UCS at 28 days (MPa)	Modulus E at 28 days (MPa)
Clean sands and	7 - 15	400 - 1'000
Silty sands	4 - 8	400 - 8.000
Silty clays	1 - 3	200 - 500
Soft clays	0.5 - 1.5	100 - 300
Stiff clays	3 - 5	200 - 500

Final permeability = range between 10^{-6} m/s and 10^{-7} m/s (lower values associated to cohesive formations).

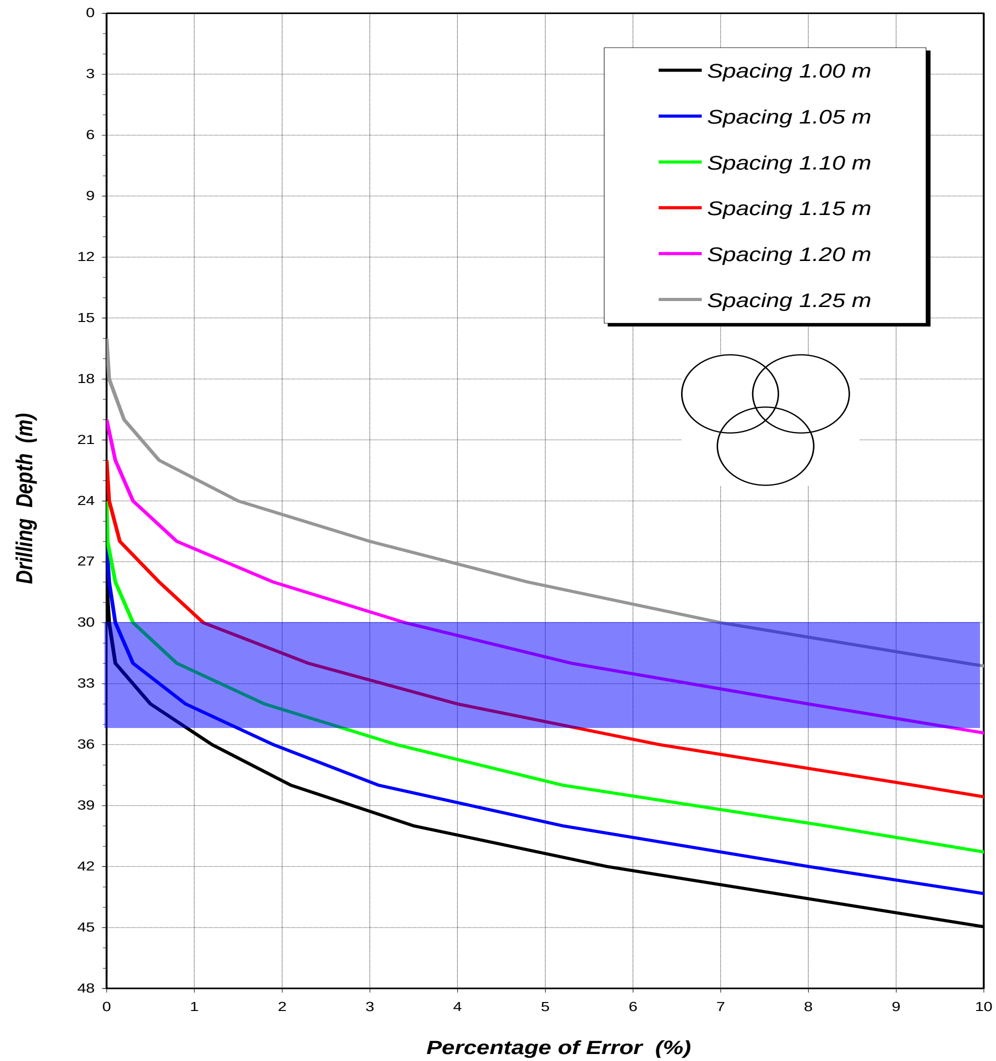
Jet Grouting

Probability 95%



Depth = 30 m

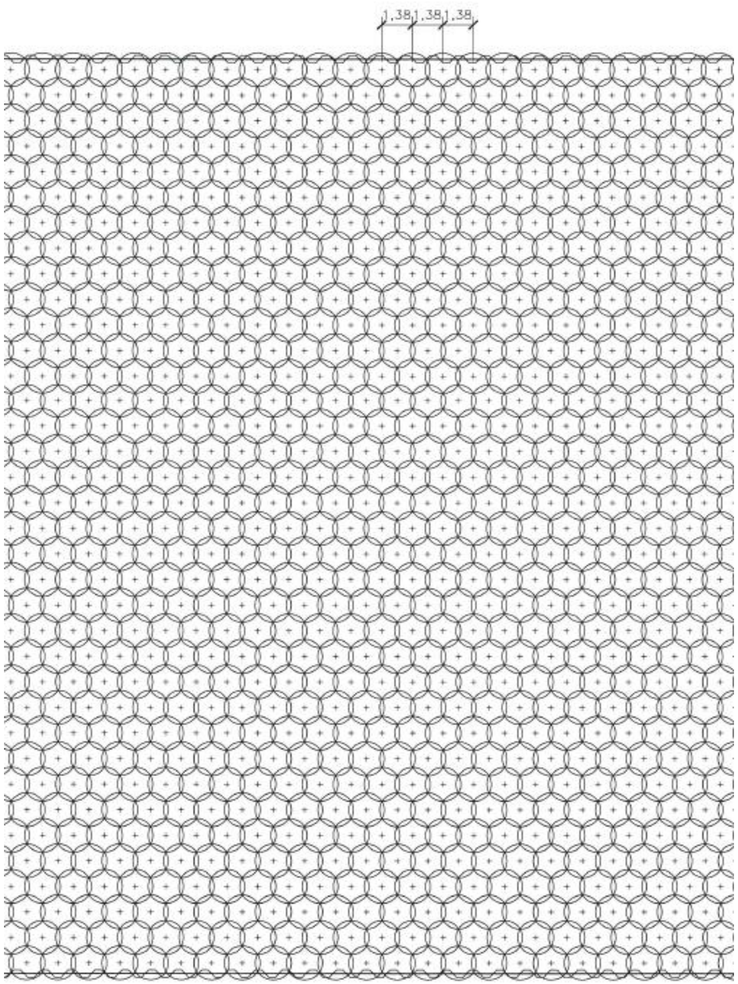
Bottom Plug by 1800 mm Jet Grouting Columns
Vertical Deviation = 0.8%



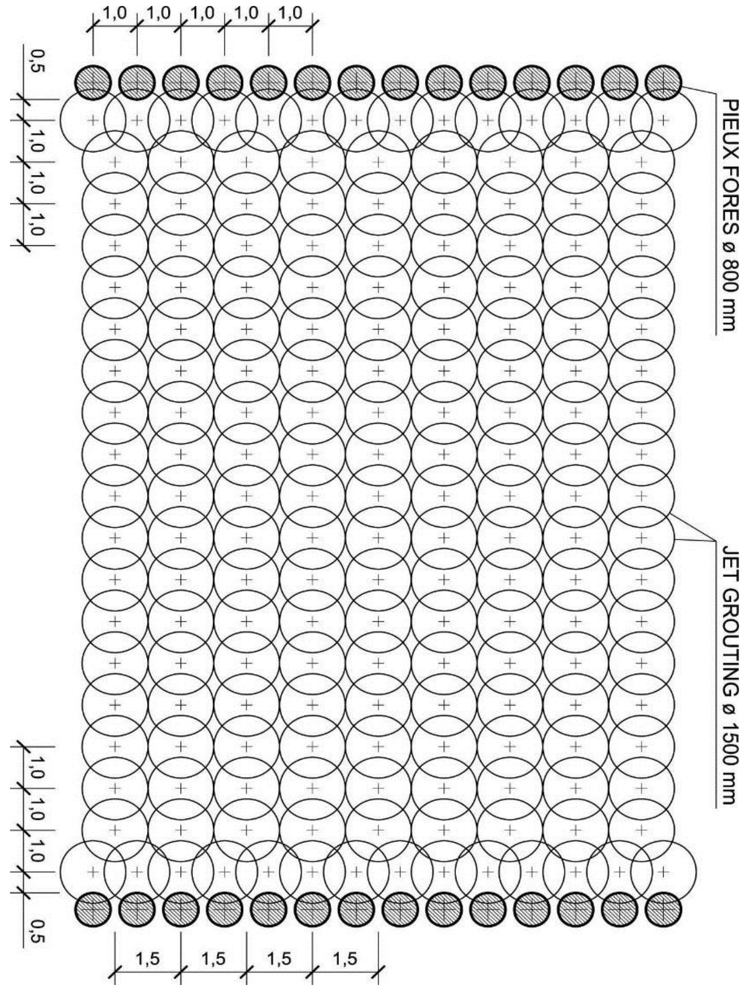
Jet Grouting

Jet Grouting bottom slab
Typical patterns

Hydraulic



Structural



1. *GENERAL VIEW*

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4. CASE HISTORY

QC/QA and MONITORING SYSTEM

Before execution

- Laboratory tests
- Test fields

During execution

- Rheology
- Return flow
- Record and CONTROL parameters
- Borehole deviation
- 3D as-built

After execution

- Core drillings
- Destructive drillings
- Pumping tests
- Thermal detection
- Geo-electrical, cross hole and seismic test

QC/QA and MONITORING SYSTEM

Before Execution - TRIAL TEST

A full scale trial test should be performed on-site, to assess the suitability of the selected method, the parameters and type grout mixture to achieve the design requirements, QC/QA procedures.

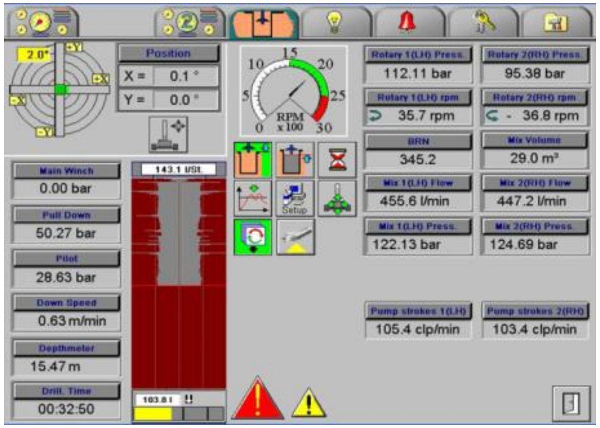
The aim is to minimize the uncertainties and verify the design criteria.

The trial columns shall be installed in the same soil and in the same conditions as the real work.

The typical test is performed by changing the working parameters to explore a range of possibilities.

Quality controls during the operational phase

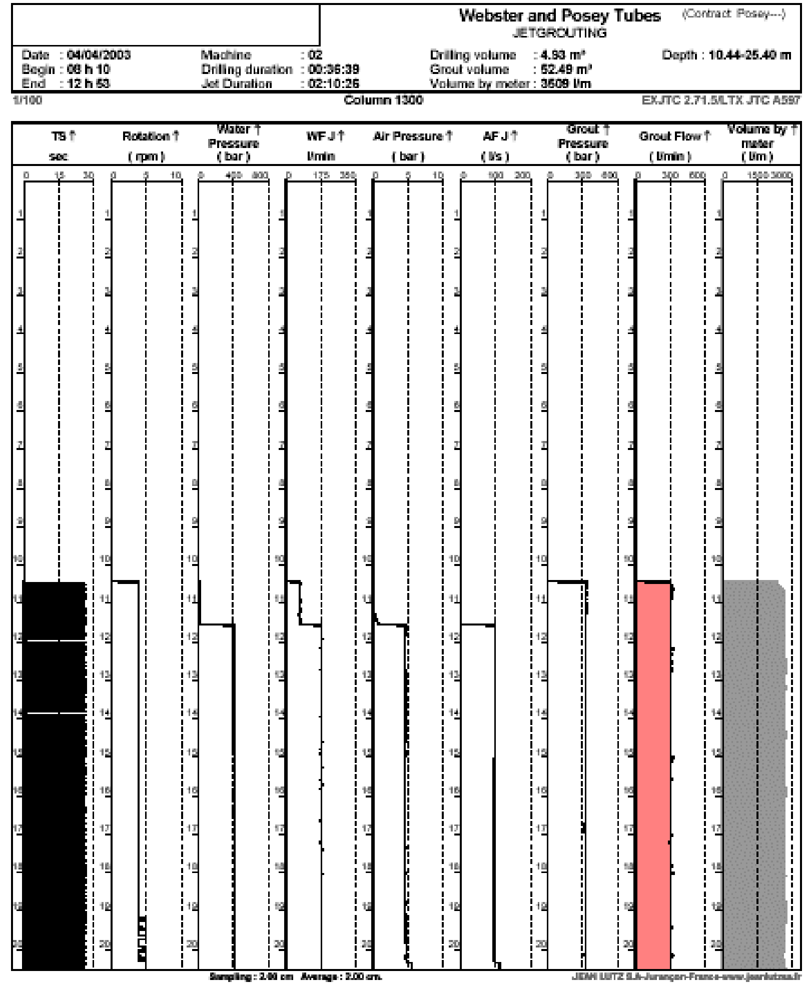
- Controls on the fresh mixture (i.e. volume weight and Marsh density);
- Controls on the regular and constant discharge of the "spoil" material from the hole;
- Controls on the fresh spoil material (i.e. volume weight);
- Controls on the injection parameters (rotation speed and rods' extraction speed, pressures, flows and volumes of the fluids employed).

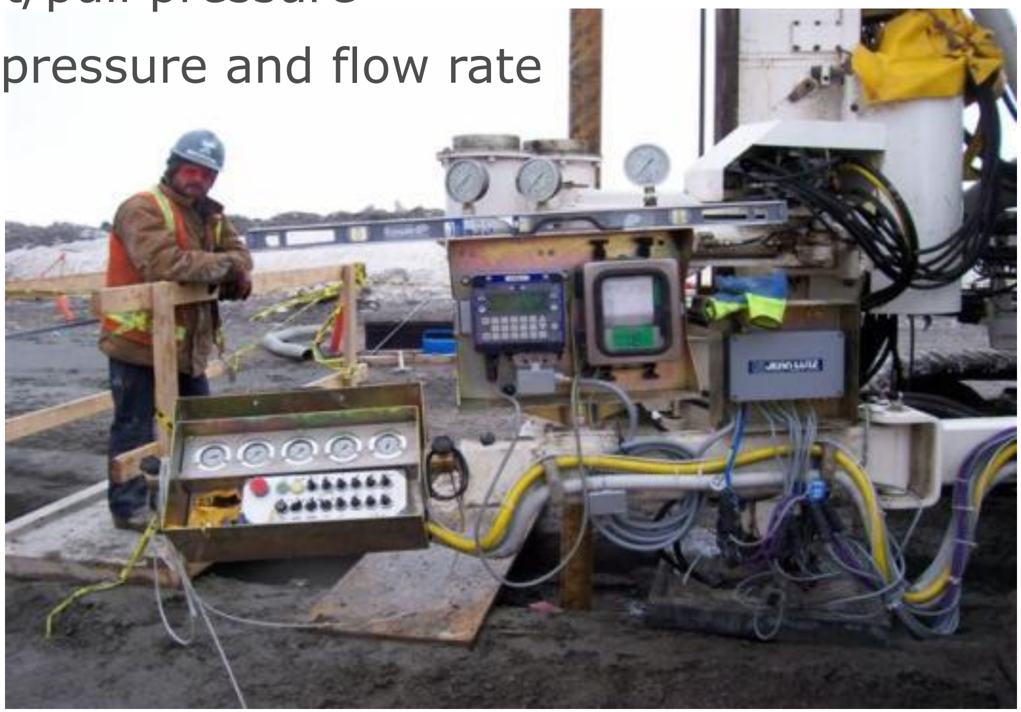


MONITORING SYSTEM

The drilling/jetting parameters of jet grouted elements can be recorded by a recording device. The main parameters are:

- drilling/lifting speed
- rotation speed
- thrust/pull pressure
- fluid pressure and flow rate





The device can automatically control the lifting speed of the machine

VERTICALITY CONTROL SYSTEM

The verticality check can be performed in all the columns using some special device:

- ❑Inclinometers or gyro systems driven inside inner passage of the jetting rods
- ❑DPS or TIGOR system

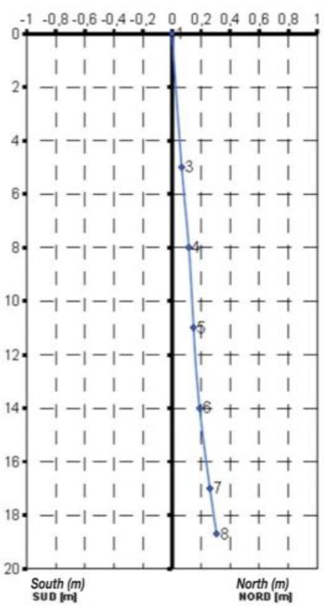


Diagramma scostamenti Nord-Sud - Y
North-South Y Deviation

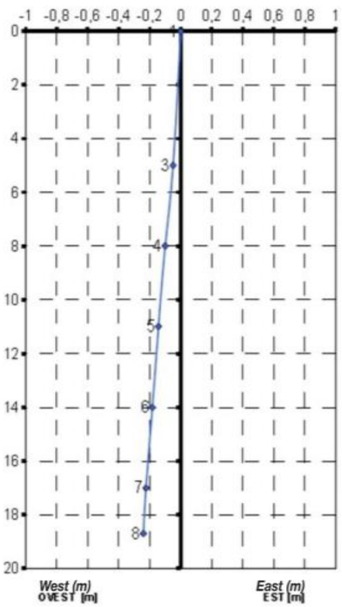
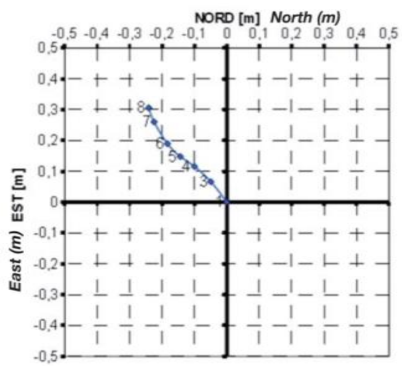
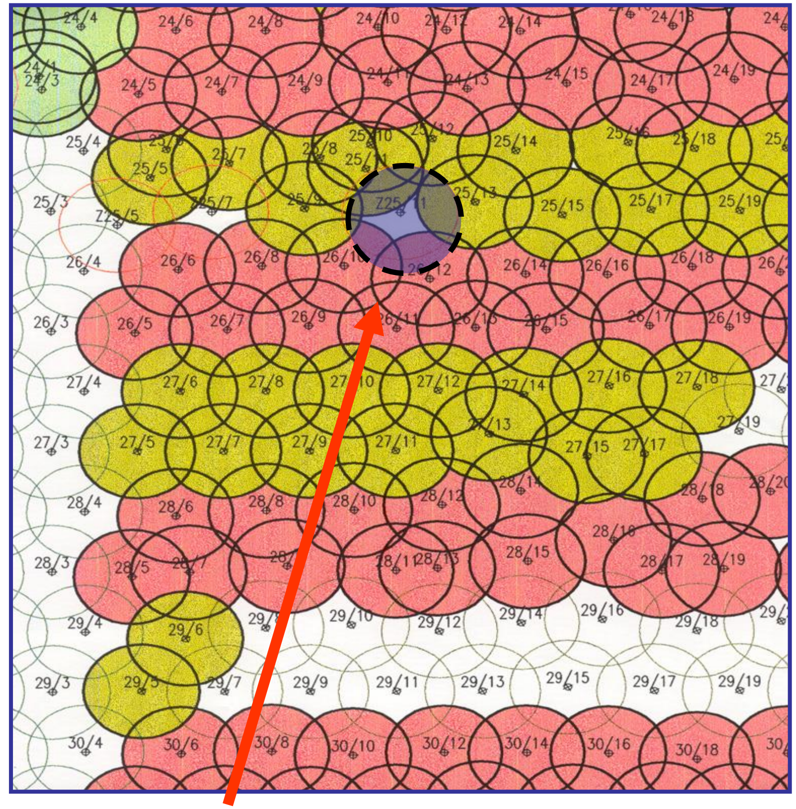


Diagramma scostamenti Est-Ovest - X
East-West X Deviation





ADDITIONAL COLUMN

The as-built drawing allows to plan the execution of additional columns

GPS SYSTEM

The GPS system allows to set up the drilling rig on the right spot, in a precise, easy and quick way, without the surveyor continuous assistance.

Easy control on the already installed columns, avoiding the risk to skip columns and leave not treated zones or install twice the already installed columns.