“ Technology and innovation “

Sprayed concrete for rock support and permanent linings

&

Injection technology for water ingress control in tunnels

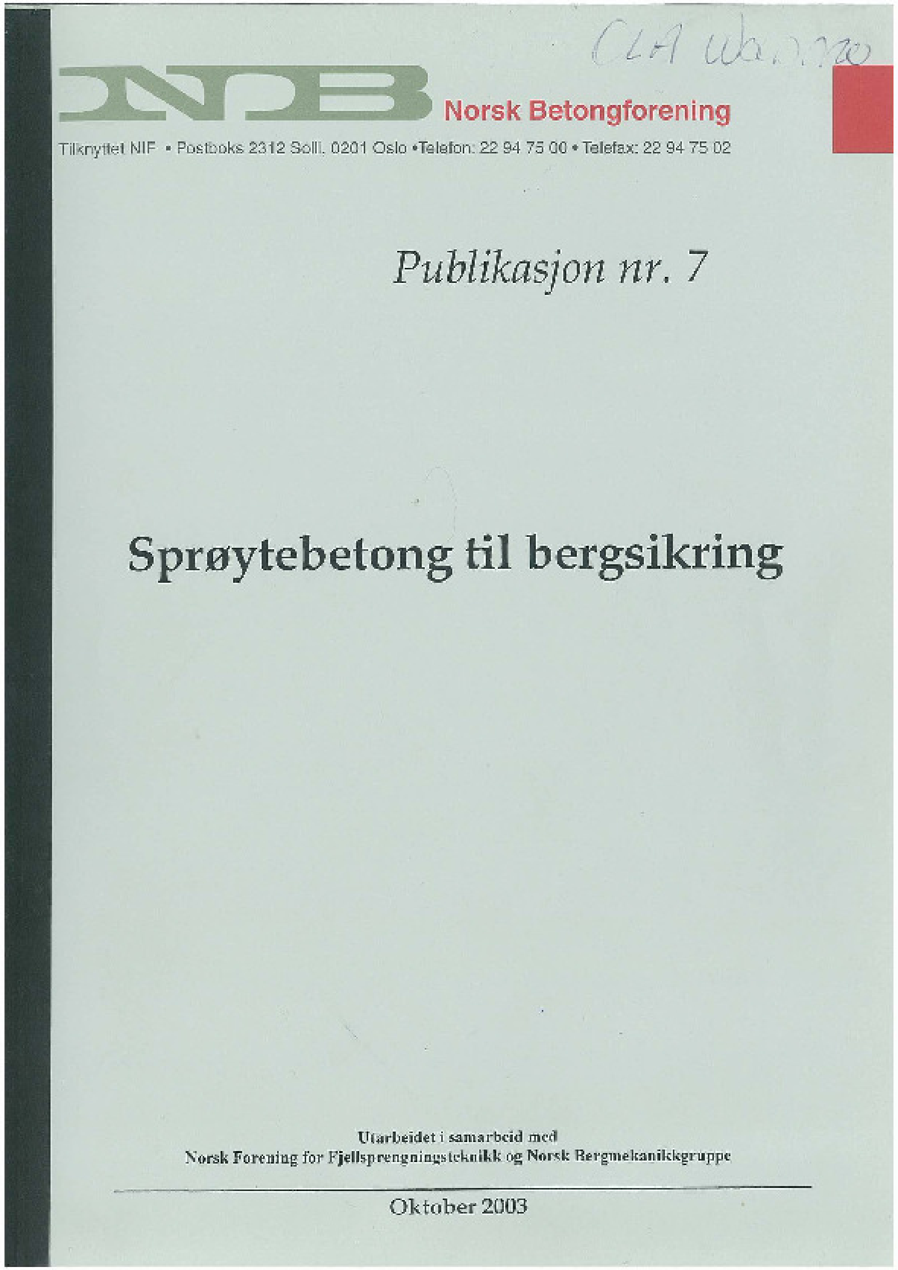
Singapore 18th February 2009

Ola Woldmo

Woldmo Consulting Ltd.

- Probe drilling and pre-injection of the rock mass
- Computer controlled high capacity drilling
- SSE explosives and blasting techniques
- Ventilation technology
- Profile control by scanning
- Temporary & final rock support by rock bolts, steel arches and fibre reinforced sprayed concrete

concrete



- First issue 1979
- Major revision 1993 (Englis
  version)
- Recognised and used by th
  Norwegian industry
- Influencing the EFNARC guideline
- Editorial work ongoing to meet new European CEN standards
- Release 4Q 2009 (English

National requirements for person in charge of sprayed concrete works is stated in Norwegian Standard NS 3465 and 3429 chapter G 75: Sprayed concrete for rock support

Sprayed concrete supervisor

Sprayed concrete works including all parts in the process should be controlled and managed by a certified supervisor

Three classes of certification:

Grade 1) Sprayed concrete works with limited structural impact and low complexity, temporary rock support

Grade 2) Sprayed concrete works with structural impact and normal complexity, temporary and final rock support

Grade 3) Sprayed concrete works with high structural impact and high complexity, final structures under severe conditions subsea tunnels large span caverns e.g.

Norwegian Concrete Association

Requirements to be certified

Education) Varies for the different grades of certification, grade 1-2 require adequate formal education, grade 3 require a B.Sc degree

Practice and experience) Minimum 3 years and the candidate must have been direct involved in sprayed concrete works. Experience to be documented.

Training and testing) 3 + 3 day full day training course including theory, practical lab. works and final test in writing including 50 questions. Basic concrete technology + sprayed concrete technolog

Certificate) Upon passing the test the candidates obtain certificates in the classes they are qualified for.

Basic concrete mix design

concrete for temporary and permanent works shall confirm to the European EN 206 norm.

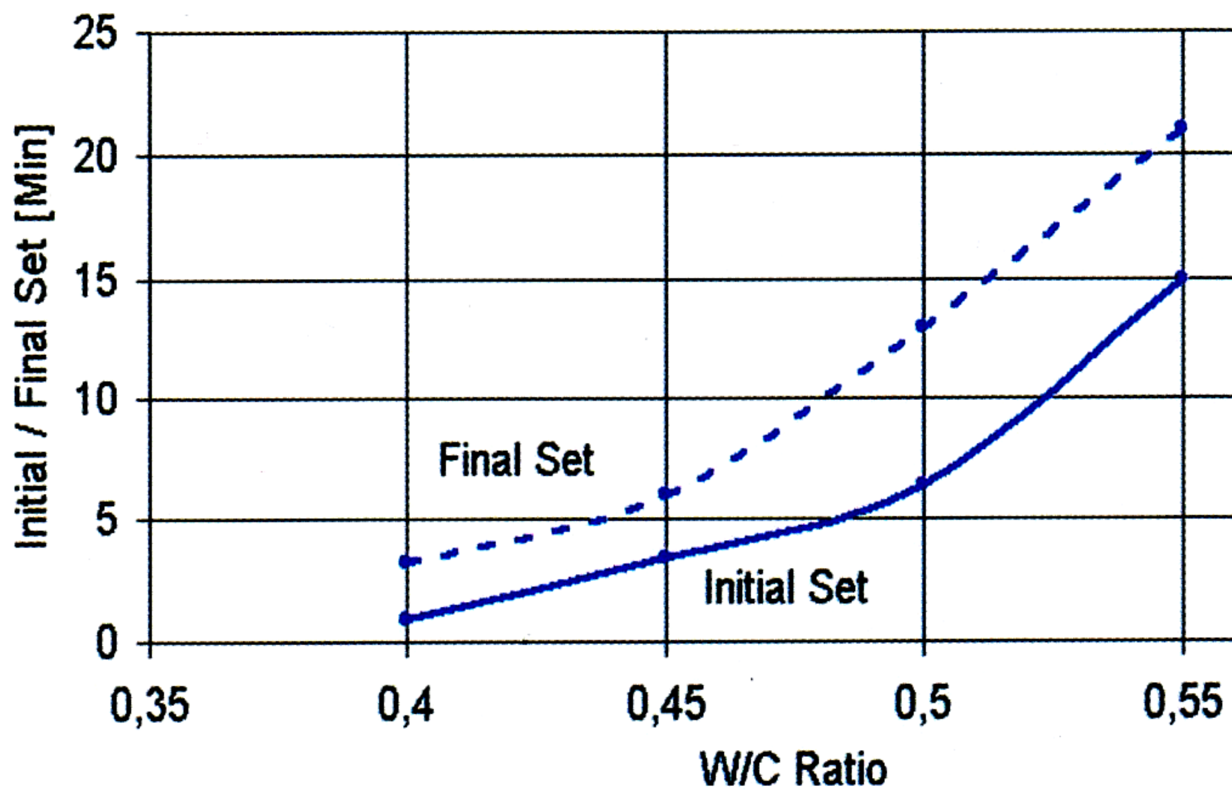
- CEM I 42.5 or CEM II 52.5
- Minimum cement content 420 kg m3
- Maximum 8 mm aggregates. Natural shaped aggregates is superior to crushed aggregates .
- Clean water without fines, salts or high/low pH value
- 5-10 % of silica fume in the mix.
- Steel or synthetic fibers for reinforcement

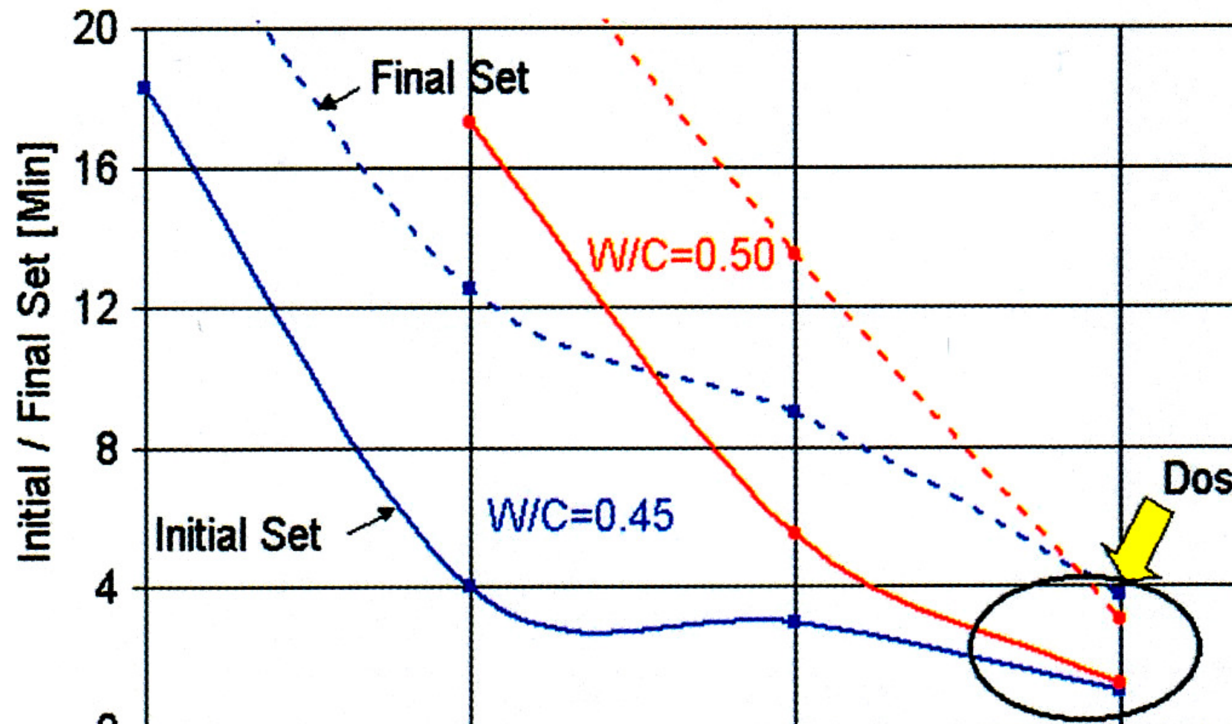
- High performance plasticizer o PCE basis
- Retarder to prevent hydration before spraying
- Concrete improver for bond an increased durability

W/c ratio is critical to

- **Early setting and strength development**
- Long term strengths
- Long term durability - resistance to chemical attack

W/c ratio should be less than 0.45, and preferably be 0.4





rength requirement for permanent prayed concrete linings

470 kg cement (incl. 25 % PFA)

30 kg micro silica

1480 kg sand (d-max 8mm)

225 kg water

7 kg macro PP fibre

3-4 kg PCE plasticizer

5 kg internal curing

~200 mm slump

Concrete class:	B35 / M40
W/C ratio	< 0.40
Early strength:	1 MPa / 1
	4 MPa / 6
	18 MPa/24
Final strength:	45 MPa (c

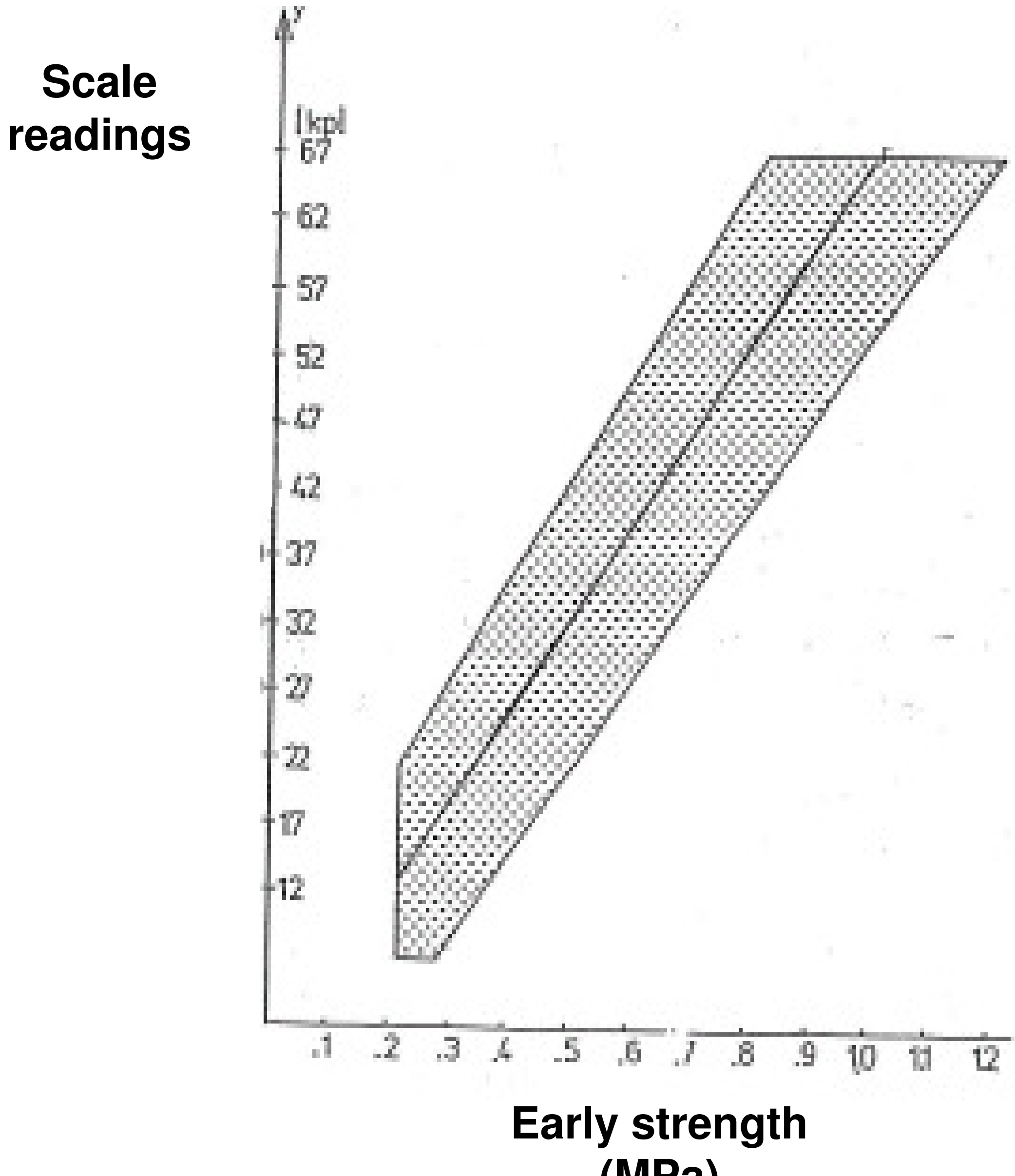
able to achieve high durability

Not spray

Good spray


Meynadier

sults


Scale readings
[kp]
67
62
57
52
47
42
37
32
27
22
17
12
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
Early strength (MPa)

Time	Strength	Method
0 – 1 hr	0- 1,5 MPa	Penetration needle
1 – 12 hr	2 – 10 MPa	Hilti - nail pull out method
> 24 hr	> 15 MPa	Concrete core drilling

- Fibre content control by “ fibre count” in fresh concrete
- Energy absorption capacity testing by casting round plate tes specimens

Shooting Hilt
nails into spray
“ fresh” concre

ydraulic Coupler

Pull out testing device

- Pulling the nails out of the spray
concrete

compressive strength

Strenght developmen t with HILTI DX 450 "L". Settings 1, green cartrigdes

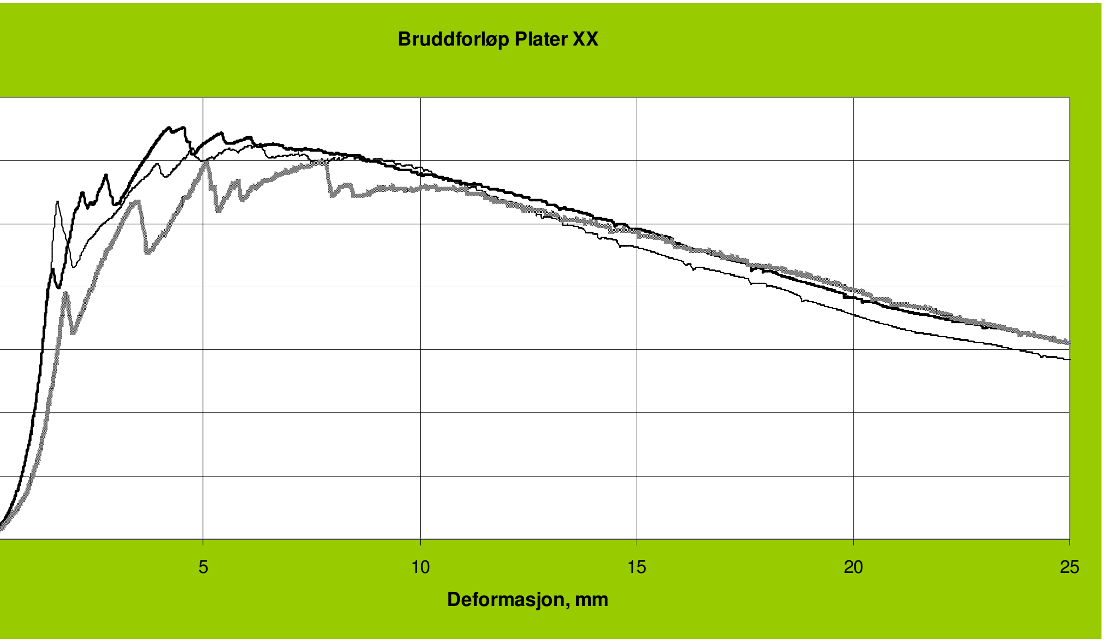
Date:	89.10.07	Test:	prøvestøp uten akselerator
Sand type:	Svellvik ? Årdal	Cement:	Norcem standard FA

Acclerator:	none
Concre temperatur:	> 20

Spalte	1	2	3	4	5	6	7	8	9	10
Test [Nr.]	Time [h]	Age [h, min]	Nails [Typ/GL]	Length (outside) concrete[mm]	Length(inside) concrete [mm]	Pullout force P [N]	correct.. P [N]	P/l [N/mm]	[N/mm]	ßD [N/mm²]
		$1 - t_0$			3 - 4		from corr.cureve	7/5	Σ 5 n	readings curve
1		18	60	20	40	1900	1854	46		
2		18	60	20	40	1900	1854	46		
3		18	60	20	40	1900	1854	46		
4		18	60	20	40	1900	1854	46		
5		18	60	20	40	1900	1854	46	46	**6,40**
1								#DIV/0!		
2								#DIV/0!		
3								#DIV/0!		
4								#DIV/0!		
5								#DIV/0!	#DIV/0!	**#DIV/0!**

Fibre performance testing. NB Publ. Nr 7

- Test specimens
  - Circular plates
- Plate dimensions
  - Diameter 600 mm,
  - Thickness 100 mm
- Bedding conditions
  - Full ring on wooden bedding
  - Inner diameter Ø 500 mm
  - Load plate Ø 100 mm



Three energy absorption classes:

Class I 500 Jouls

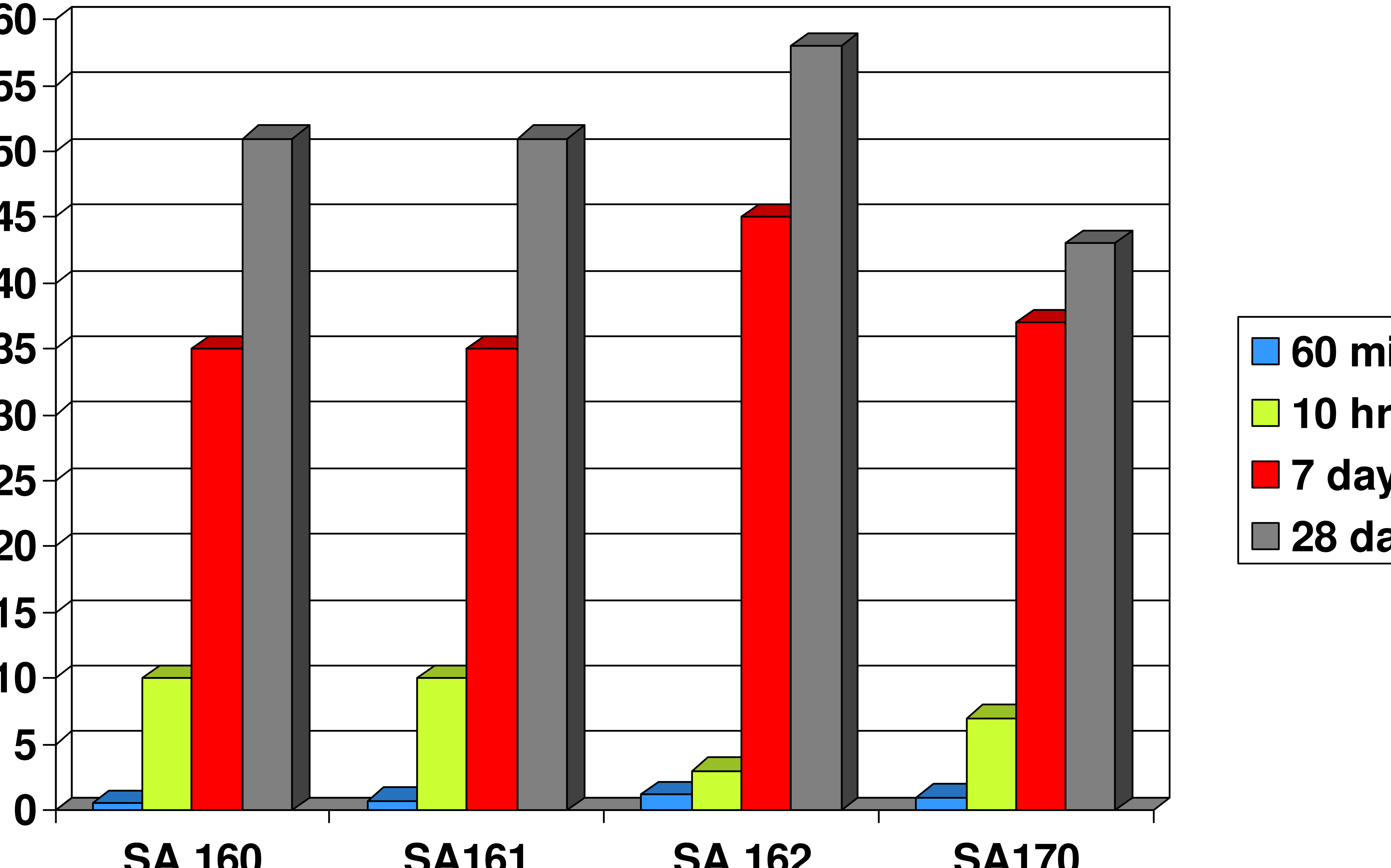
Class II 700 Jouls

Class III 1000 Jouls

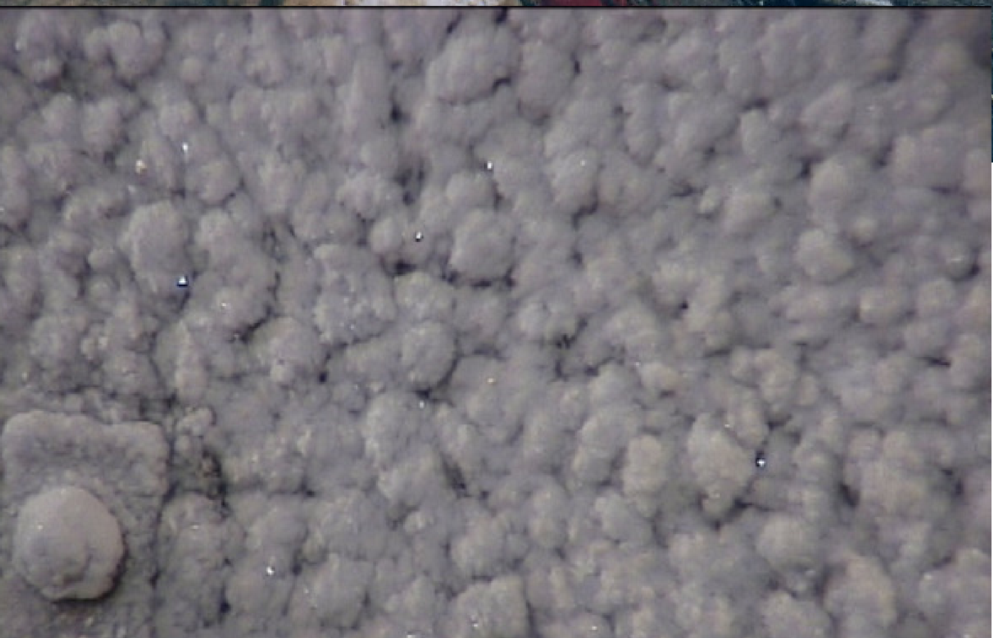
Sprayed concrete accelerators

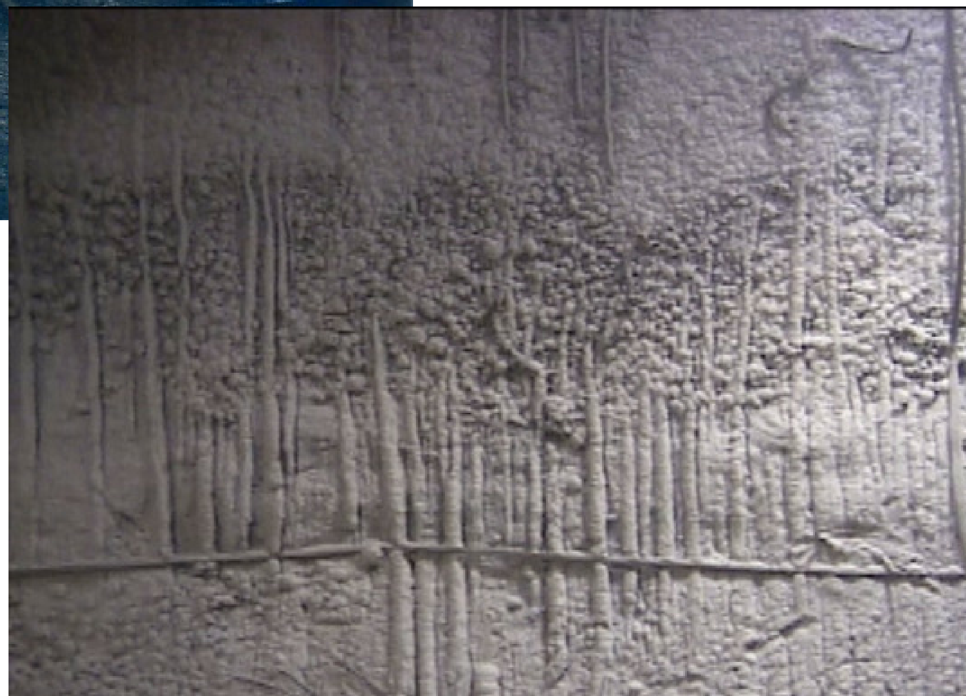
riteria for choice of AFA

- Ground conditions
- Cement reactivity
- Mix design
- Strength development requirement
- Temperature
- Final strength requirement
- Water ingress or not
- Required thickness
- Excavation method
- Preliminary or final support

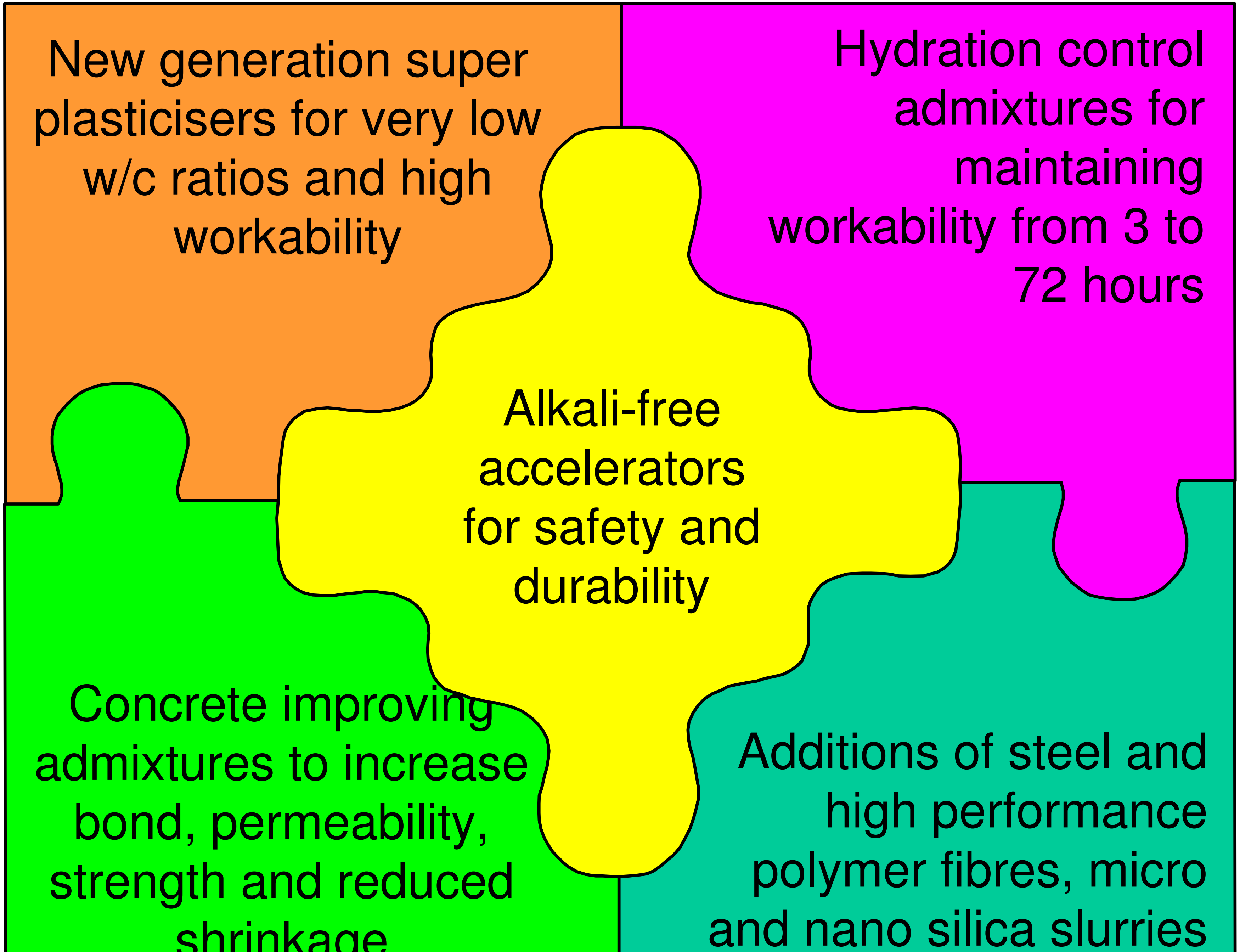

60
55
50
45
40
35
30
25
20
15
10
5
0
SA 160
SA161
SA 162
SA170

To high he
development c
evaporation, c
more ice and r
sleeping





permanent sprayed concrete



Application technique

efore starting the spraying

Check the accelerator supply. Enough pressure & dosage in a continues flow.

Accelerator temperature. Not < 20^{o}C, preferably > 25^{o}C

Concrete temperature > 20^{o}C, preferably > 25^{o}C

Wash down the surface with air & water where the rock conditions allow for this. This will improve the bond strength, reduce the risk of having “drop outs” and help reducing the dust creation.

Avoid making rebound trapping pockets. Fill completely in the first 0.5 – 1 meter, on both sides for a start.

If the substrate is of such a poor quality it can not support a 50 – 100 mm layer, go with a 10 – 20 mm “flash coat” at first.

“Weld” the steel arch / lattice girder / support structure to the rock, using the shotcrete. Use the support structure to support the concrete.

Make use of the oscillator when the “welding” is finished

Where there are large cavities to be filled, keep spraying on layers of 20 – 40mm thickness. Utilize arc effect and apply uniform layer-thickness

At the same time, use multiple passes. Build in layers 20 – 40 mm thick, where there is no water.

Where water is presenting a problem – reduce layer thickness. Increase the nozzle distance – increase the accelerator dosage. .

Spraying into "pockets", filling large cavities and spraying through steel arches, plenty of air is needed.
<u>Low air = low compaction = low density = low strengths = low durability</u>

Spraying technique

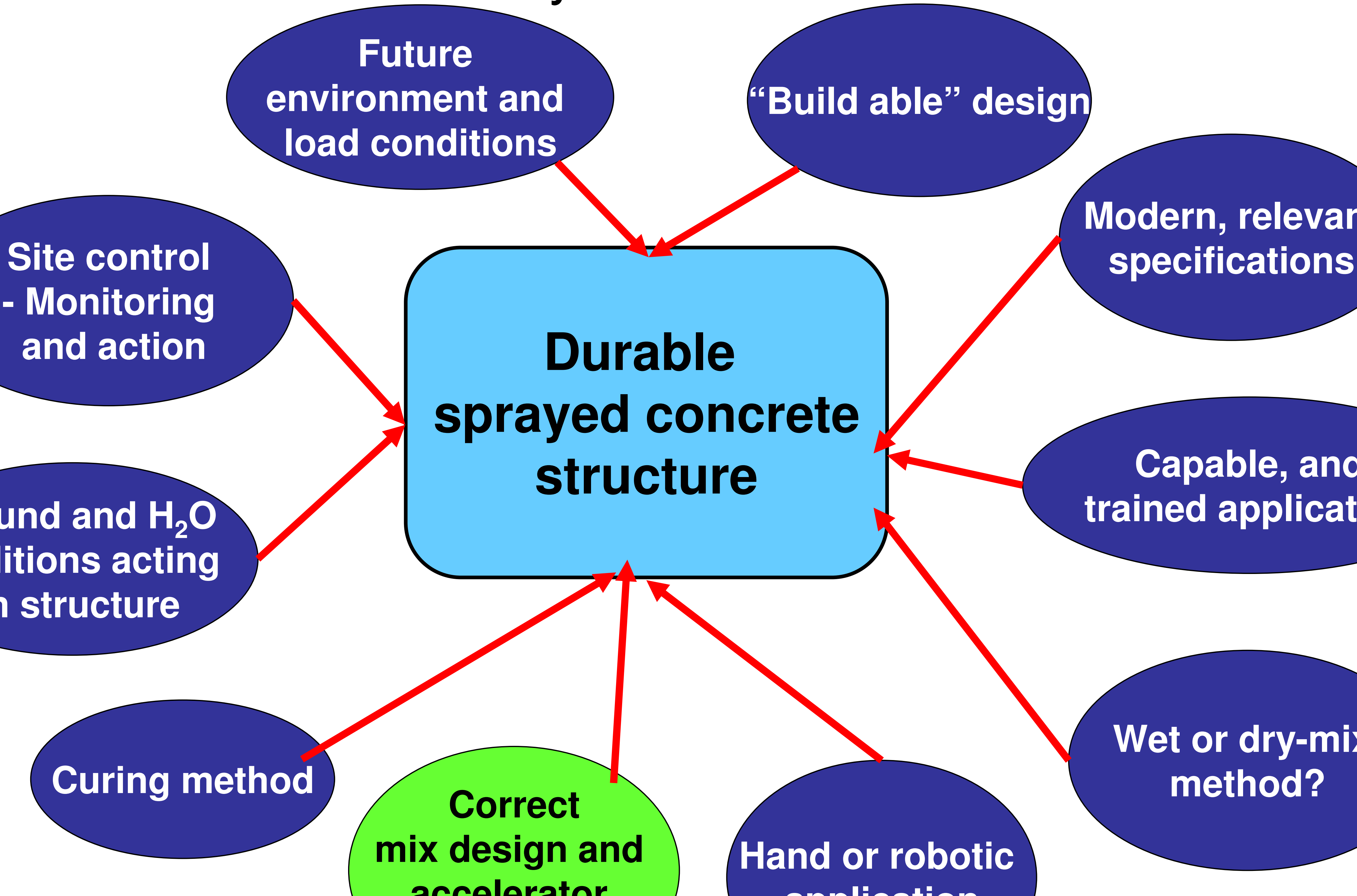
Concrete output speed.
Output speed according to size of the tunnel and operators skills. More than 25 m^3/h output, requires exceptionally good operators.

Nozzle & Boom movement.
Spraying thick layers requires lot of work from the operator.

Sufficient lights & ventilation

he same mix, but
fferent set up & air
volume/pressure

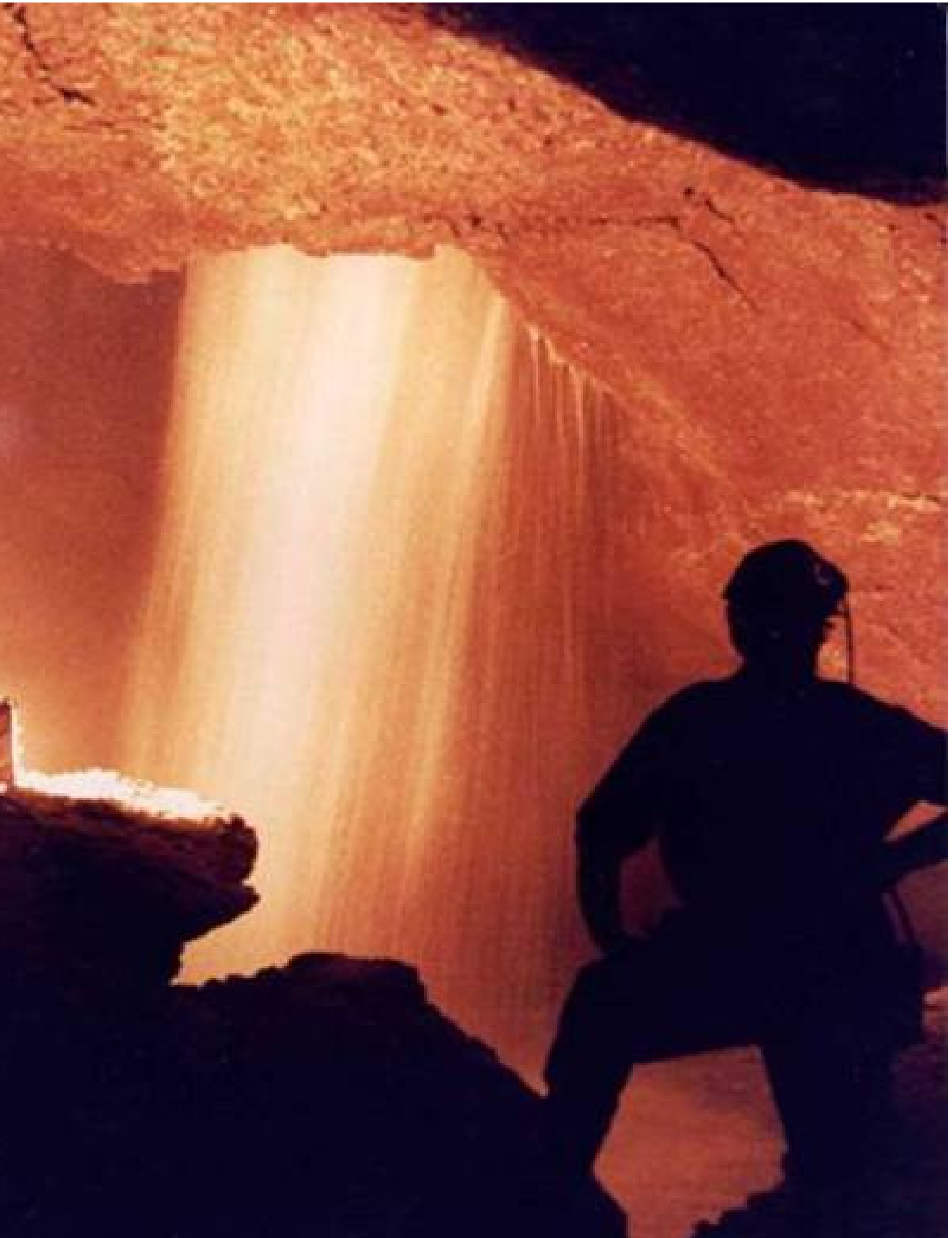
achieve durability . . .



Injection technology for water ingress control in tunnels

Definition of injection

“the introduction of a material under **pressure** into the ground or a structure with the goal of **waterproofing** and **consolidating** voids, cracks and porosity”



Safety

One of the major challenge
in tunnel excavation is
uncontrolled water ingress

Immediate flooding

Ground collapse associate
with water ingress

tter in Tunnels

Environment

Managing the environmental impa of tunnelling is cruci

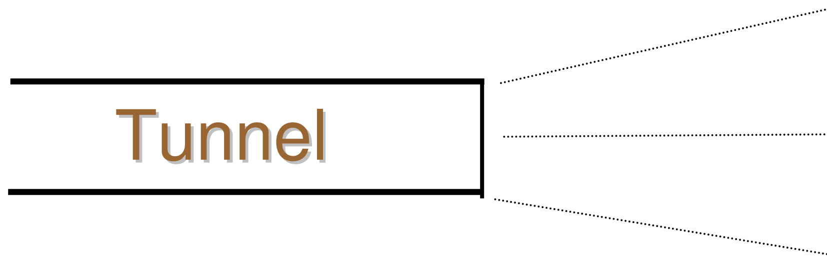
Contaminated water has to be managed

Lowering of ground-water has to be prevented in urban areas

Two procedures available

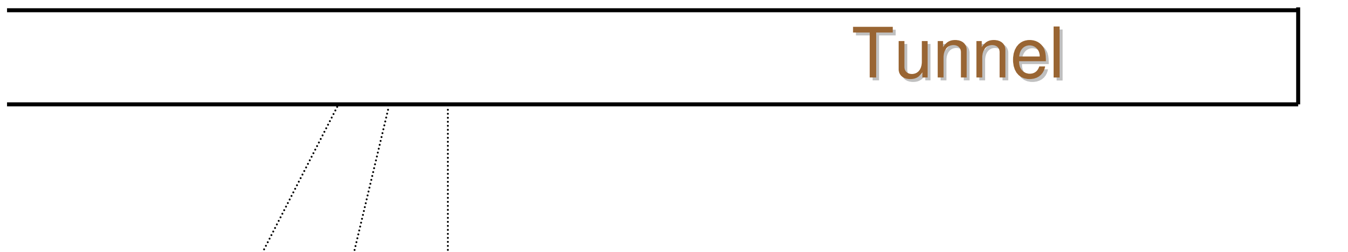
Pre-injection

In front of the tunnel face



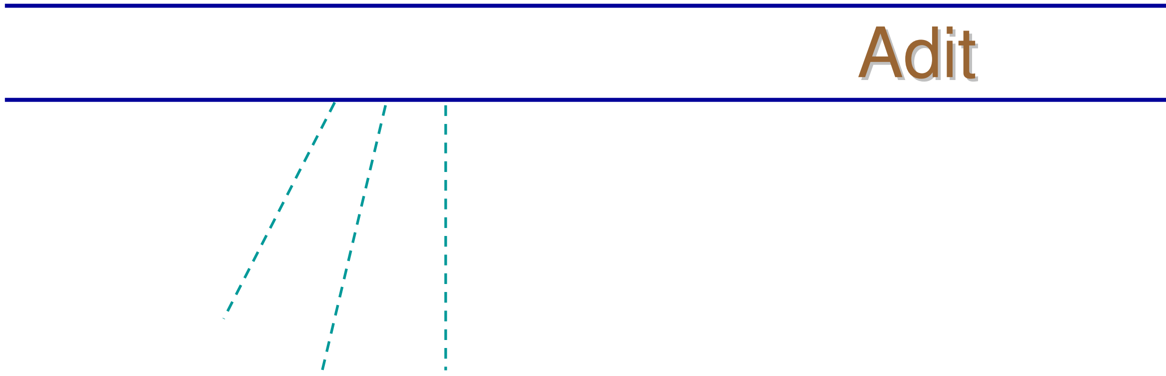
Post-injection

Somewhere behind the tunnel face



Post-injection

Somewhere behind the face



Chasing the water from place to place.

Normally relative expensive chemical resins are used

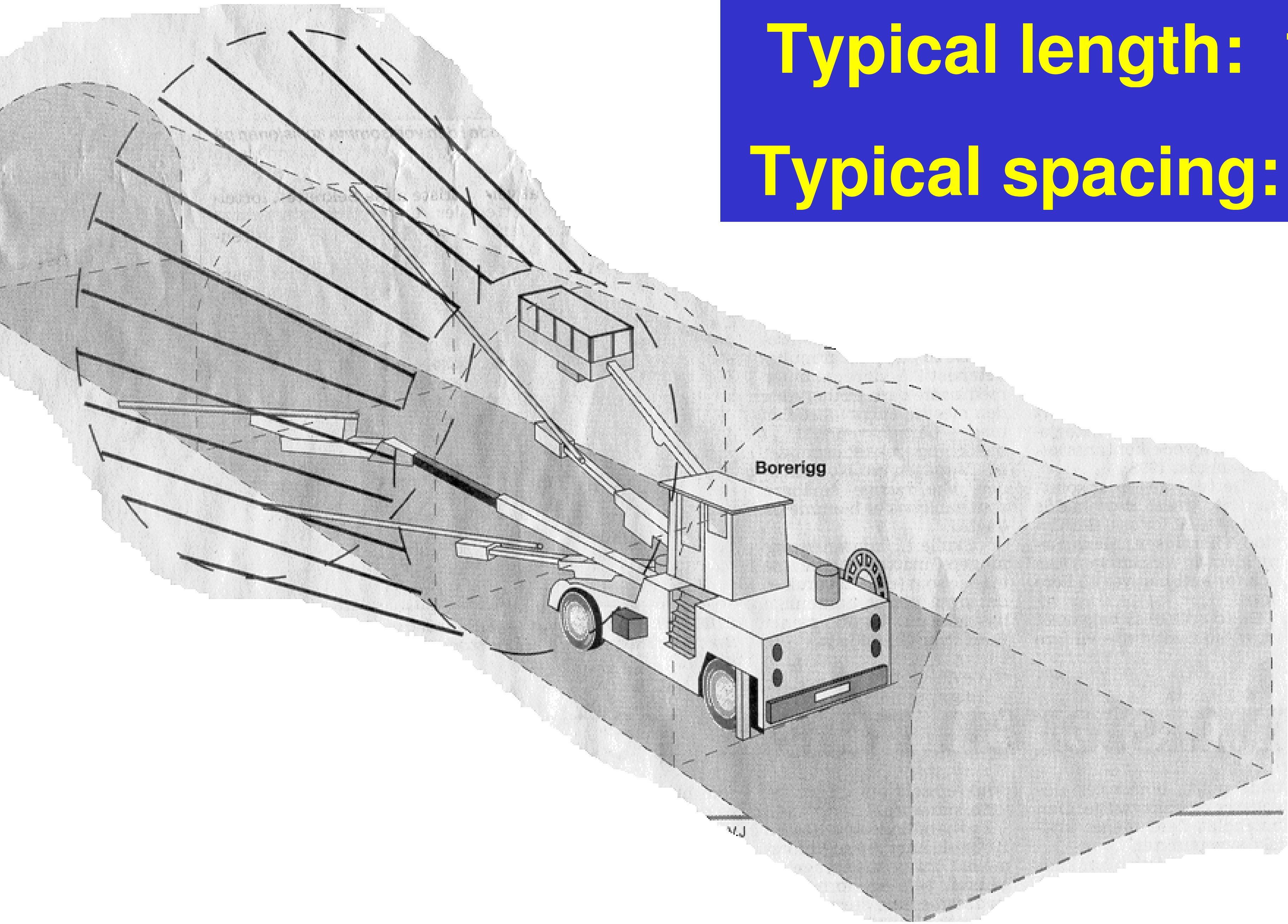
Specialized teams are employed (not always)

Karahnjukar Hydropower project, Iceland

Serious water problems in the TBM tunnel.

Post injection approach using Polyurethane

void the unexpected:
re-injection

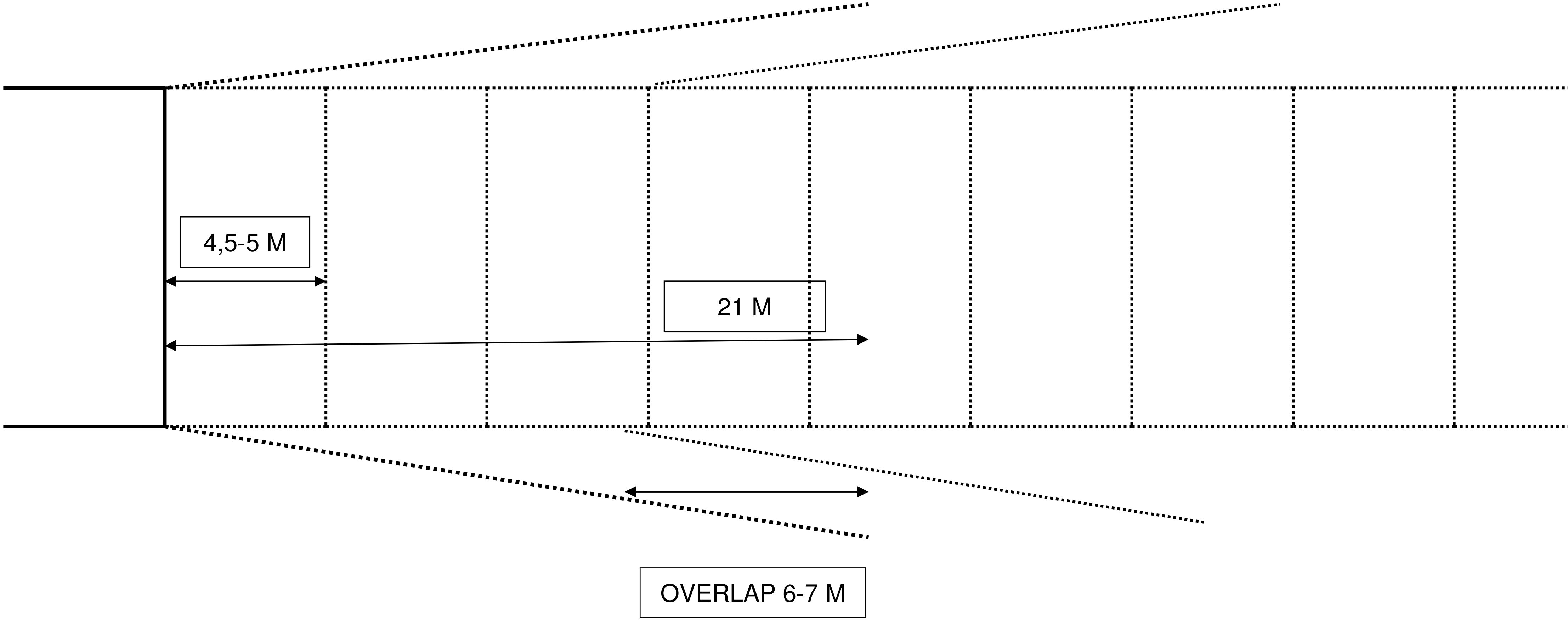


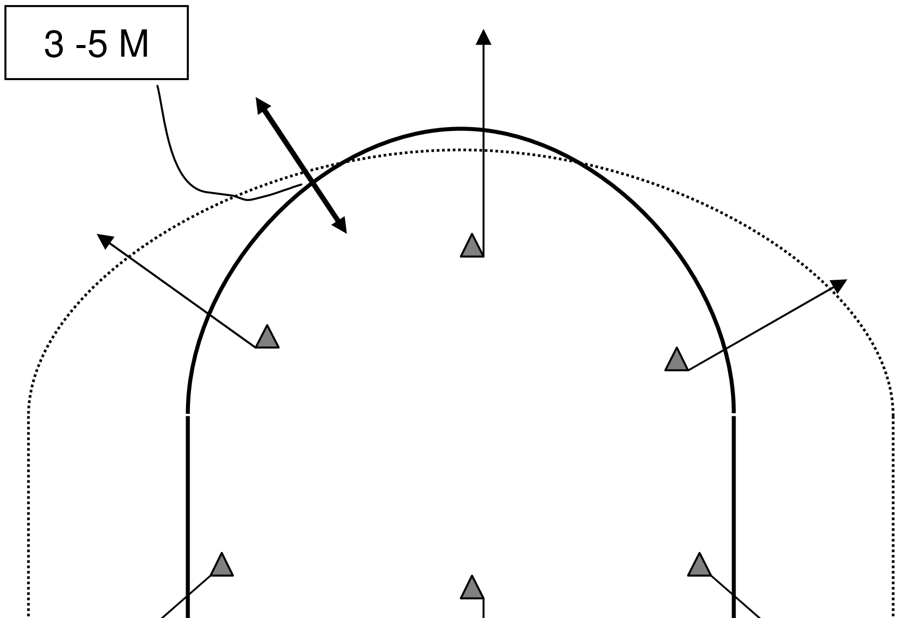
Typical length: 15 to 30 m

Typical spacing: 1 to 1,5 m

Pre-injection is far more economical than post injection!

PROBE DRILLING HOLES AND OVERLAP



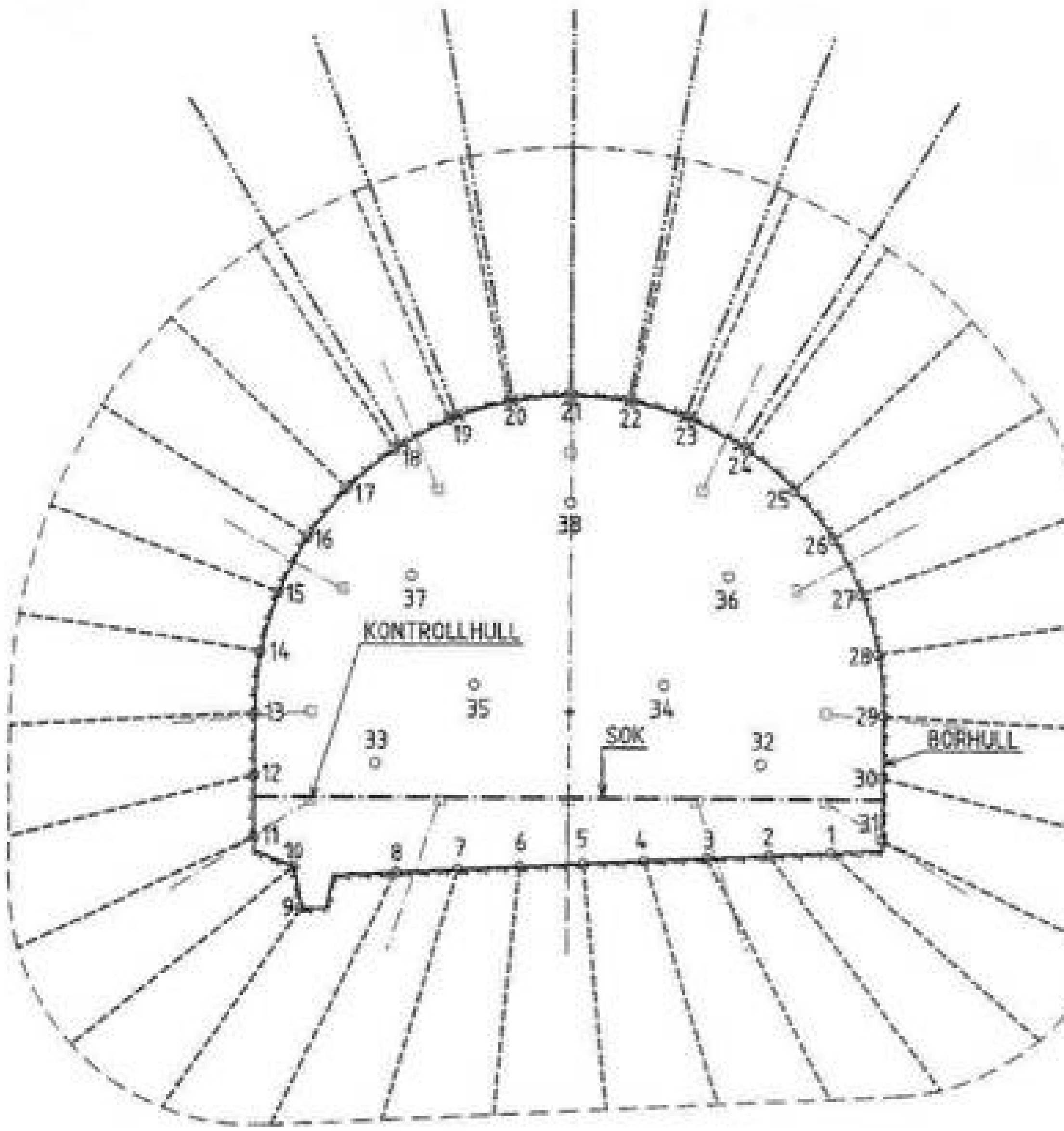


VERTICAL SECTION SEEN TOWARDS A TUNNEL FACE. PROJECTION OF EXPLORATORY HOLES AND AREA COVERED BY EXPLORATORY (PROBE) DRILLING.

THE NUMBER AND EXACT LOCATION OF THE HOLES DEPENDS ON THE WATER SEEPAGE SITUATION AND GEOLOGICAL CONDITIONS ngth of holes: 21 m

gle: 7º

tance between holes: 1,2 m



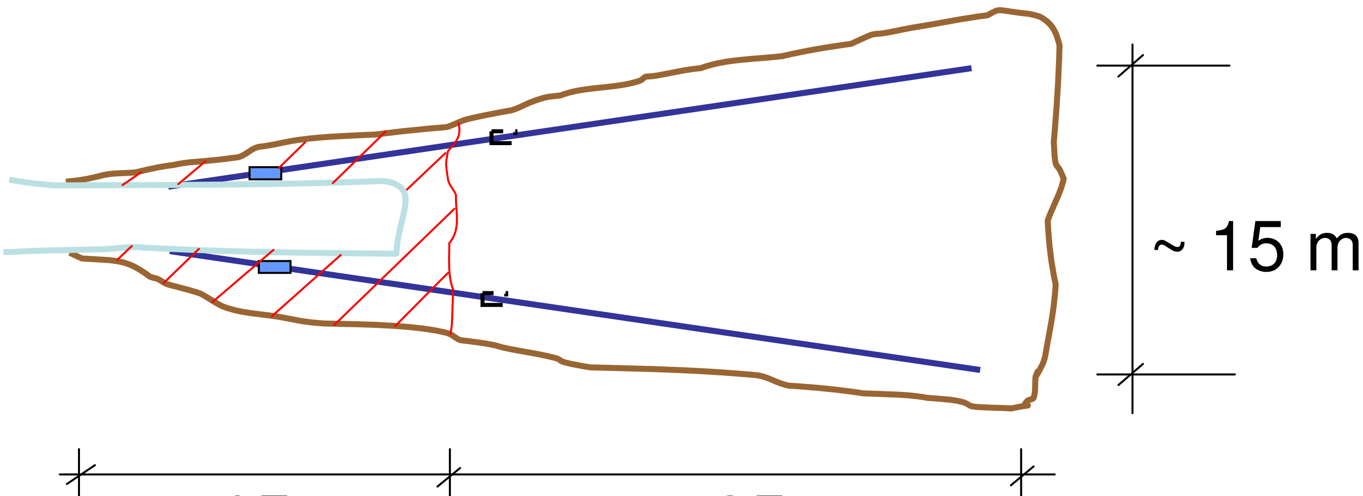
tunnels

Most TBM's are not made for pre-injection!!

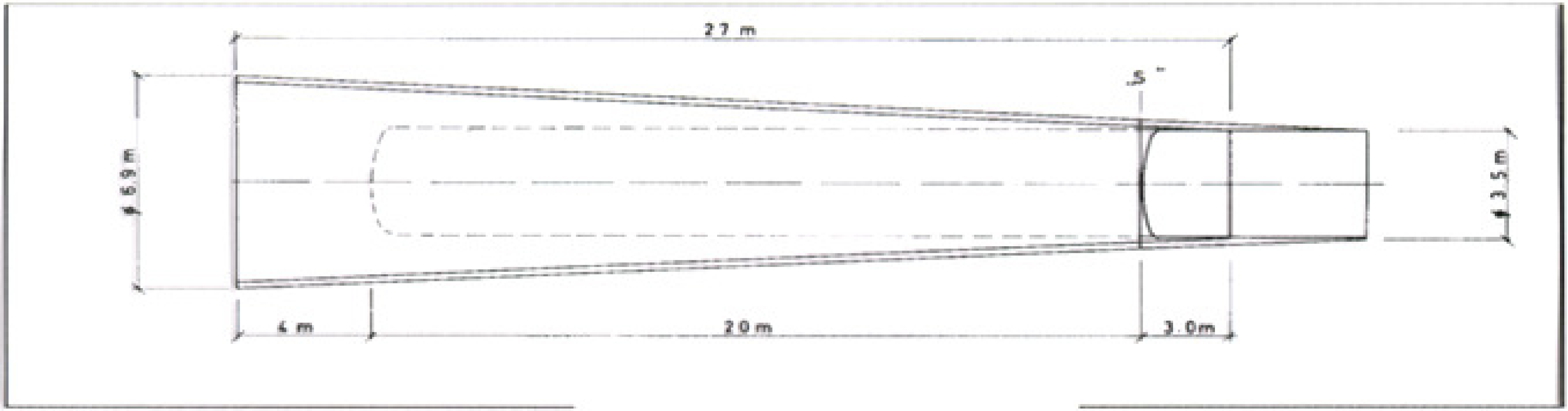
Before injection can take place, you need to be able to drill injection holes, and to guide the drill rod.

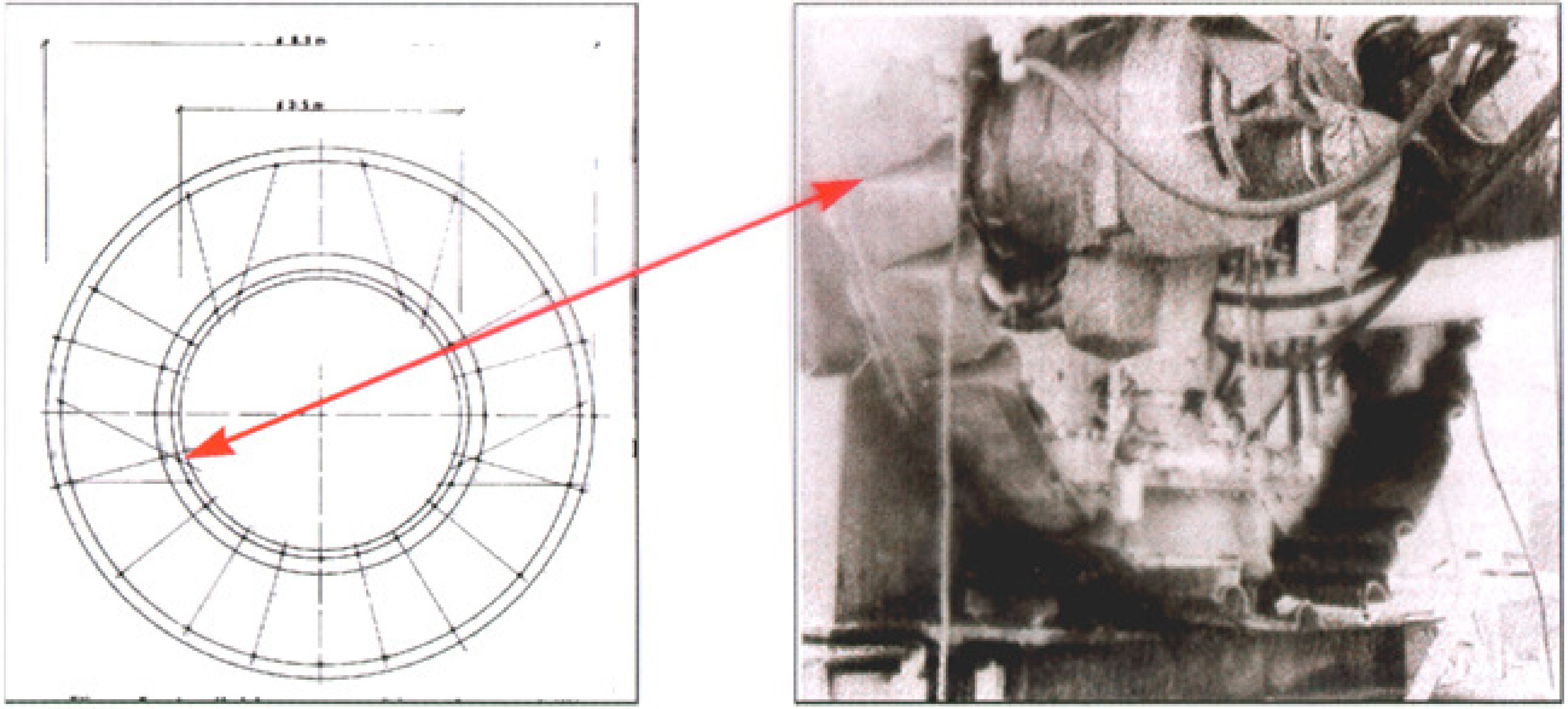
Length of holes: about 20 – 30 meters in front of the face.

Avoid parallel drilling by starting drilling to far behind the fac



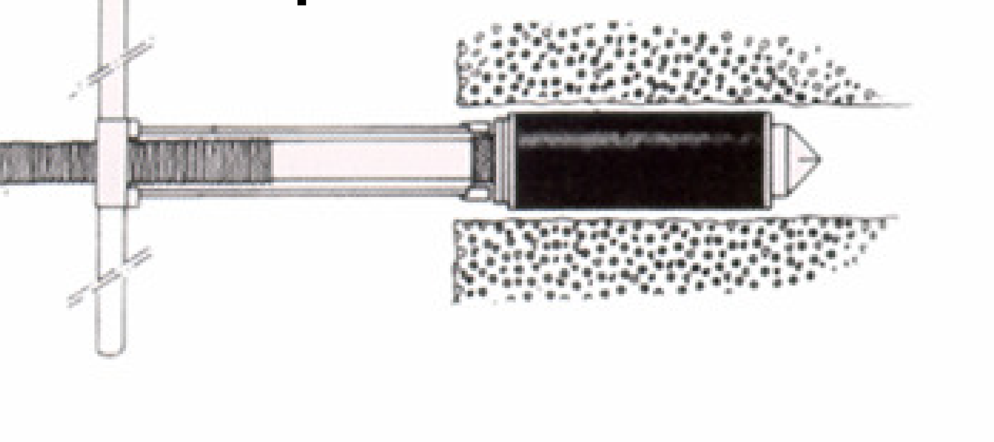
"Pre-drilling" concept





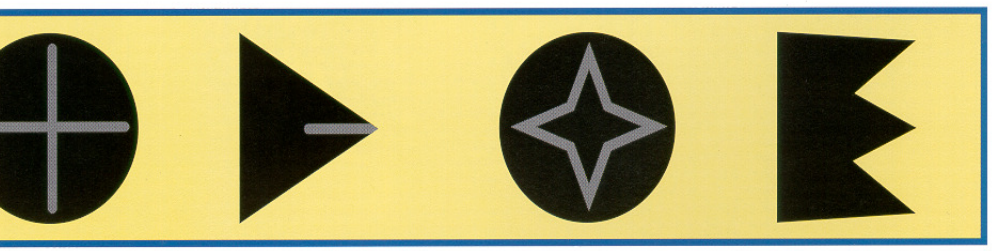
- The packers shall be placed in sound solid rock, to ensure they ar
fixed well, and to avoid grout to leak back around the packer.
- To ensure a successful injection, the packers should be fixed in
already injected rock. If not, you easily get out-leaks through crack
and fissures.
- Normally the packers are set at 1 – 1,5 meters deep.
- If packers with non-return valves are used, they should not be
mounted before they are ready to be injected. This makes it
possible to se if there is contact between the holes.

Step 1



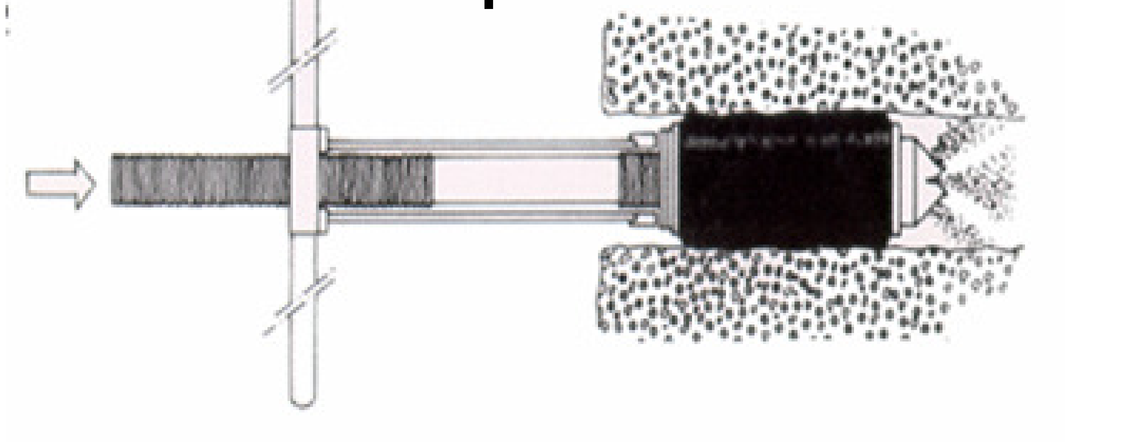
acker is attached to the injection pipes and into the drilled hole. The innermost of the two n pipes has a tightening lever for fixing the

Rubber check valve



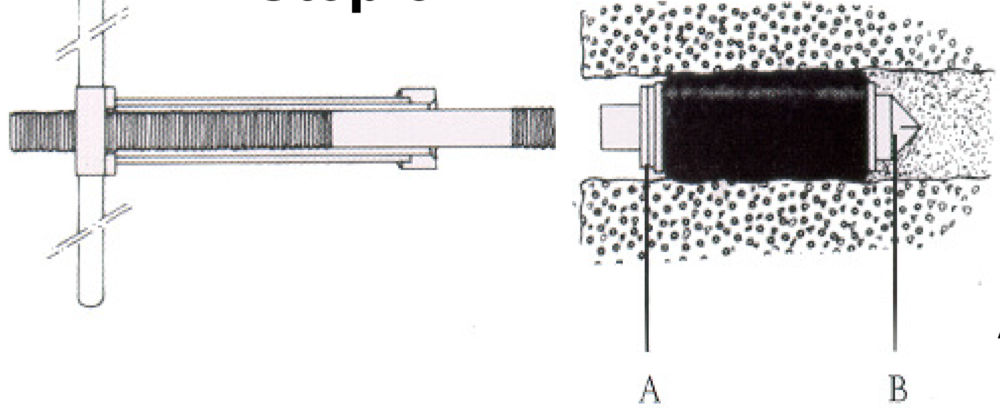
heck valve consist of conical rubber lip vulcanised he top of the packer and has two right-angled s. This means it is only possible for the substance v in to one direction. Under pressure in the te direction the valve closes.

Step 2



The packer is expanded in the drilled hole using tightening lever. Cement mixture or chemical substanc injected into the rock's crack system through the rub valve in the packer.

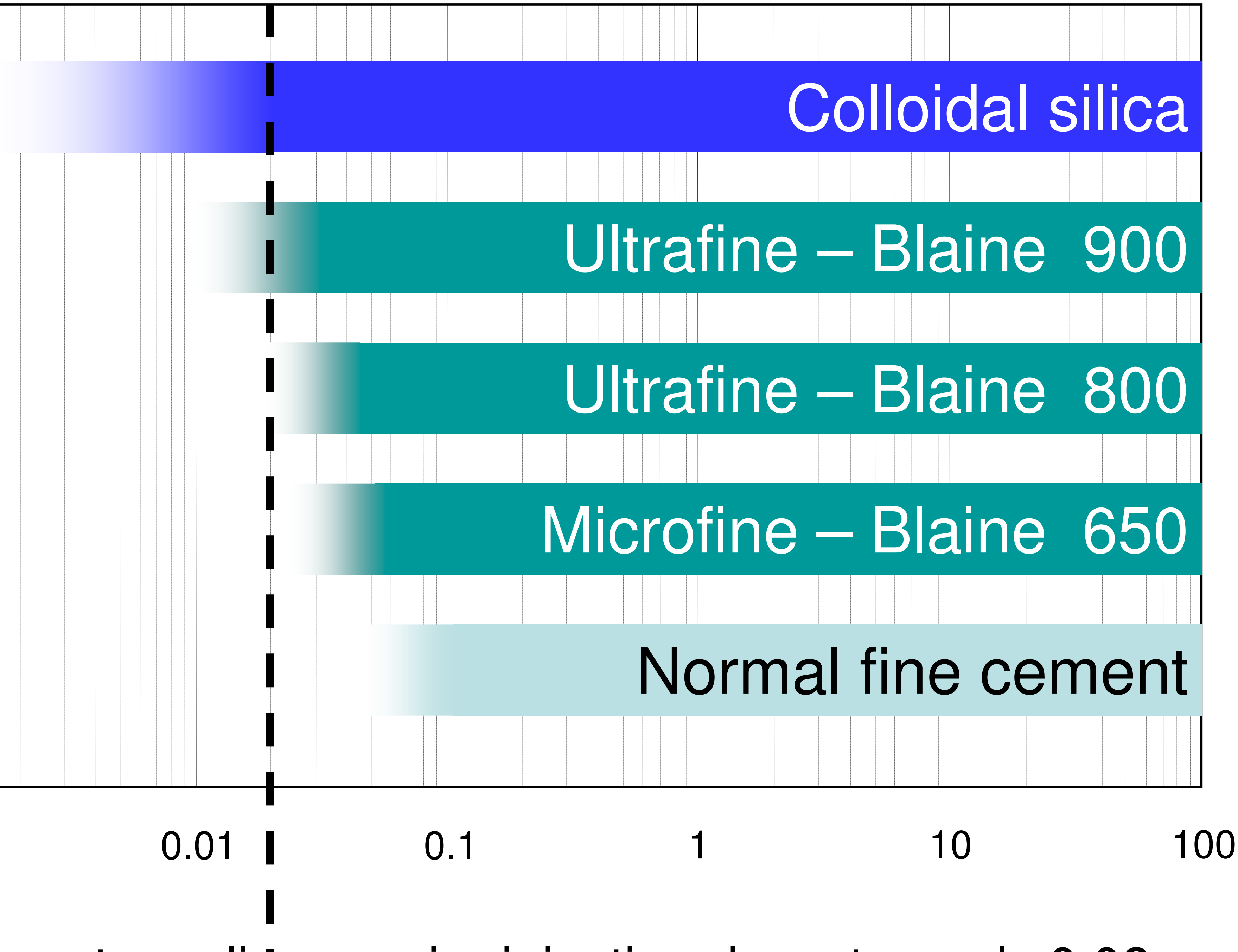
Step 3



A. Doub
B. Ru

The pump is stopped when injection is to be ended. valve in the packer is automatically closed by the pressure so that the injected substance does not ru The tightening lever is screwed back and the injection p screwed out of the packer. The pipes are taken out

Rock injection



Injection in
cracks =
3 x ceme
particle si

icrofine cement injection

Ordinary Portland Cement OPC	d 95 < 35 micron
Micro cement	d 95 < 15 micron
Ultrafine cement	d 95 < 12 micron

Plasticizer is added to improve stability and penetration
Stabilizer for long open time, and accelerator for fast setting

mportant parameters for micro cement

laine

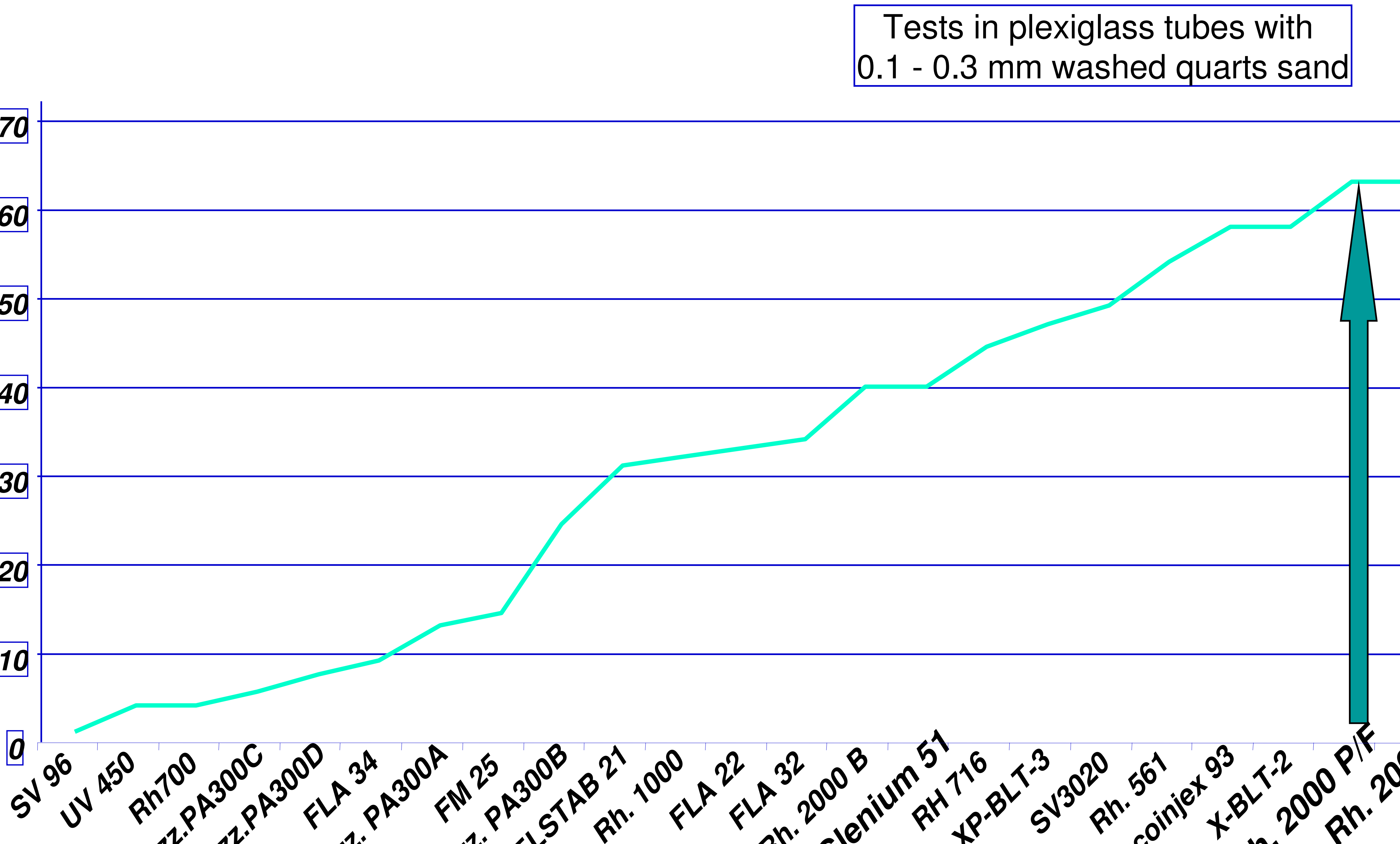
The Blaine of the cement tells us about the size of the surface of product. High Blaine - fine material.

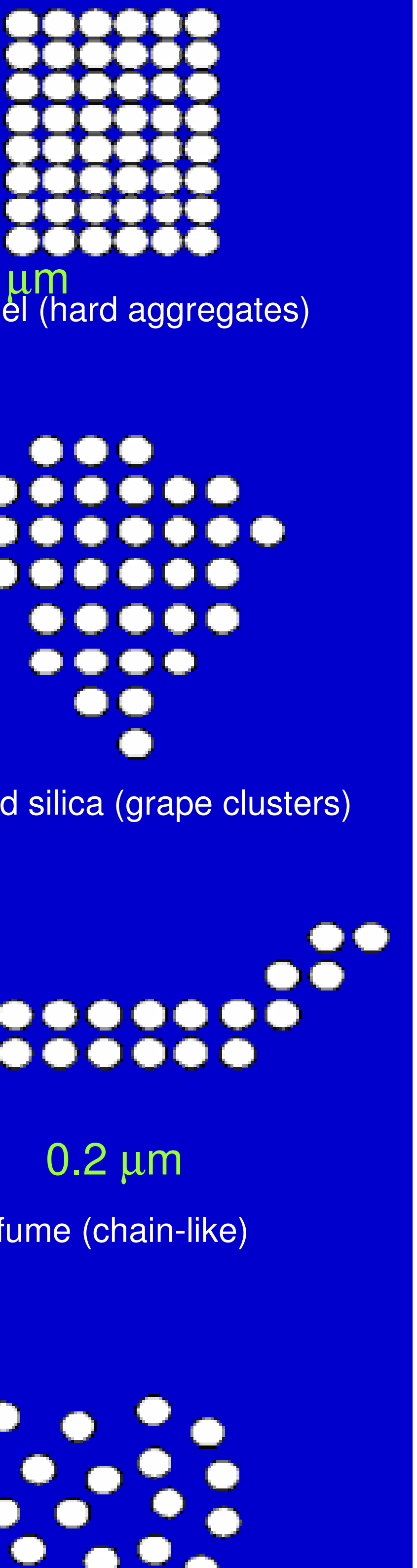
There is too much focus on Blaine.

Oversize is an other important parameter. There can be a very fin

cement, but with much over sized particles.

sticizer improve penetration





Colloidal Silica Technology

- A stable dispersion of discrete, sub-microscopi particles
- Particles are spherical and are composed of 100% amorphous silicon dioxide (non-crystalline)
- Colloidal silica production allows production of particle sizes within a few nanometers to give tailor made, consistent products for specific applications
- Very stable and environmentally friendly product

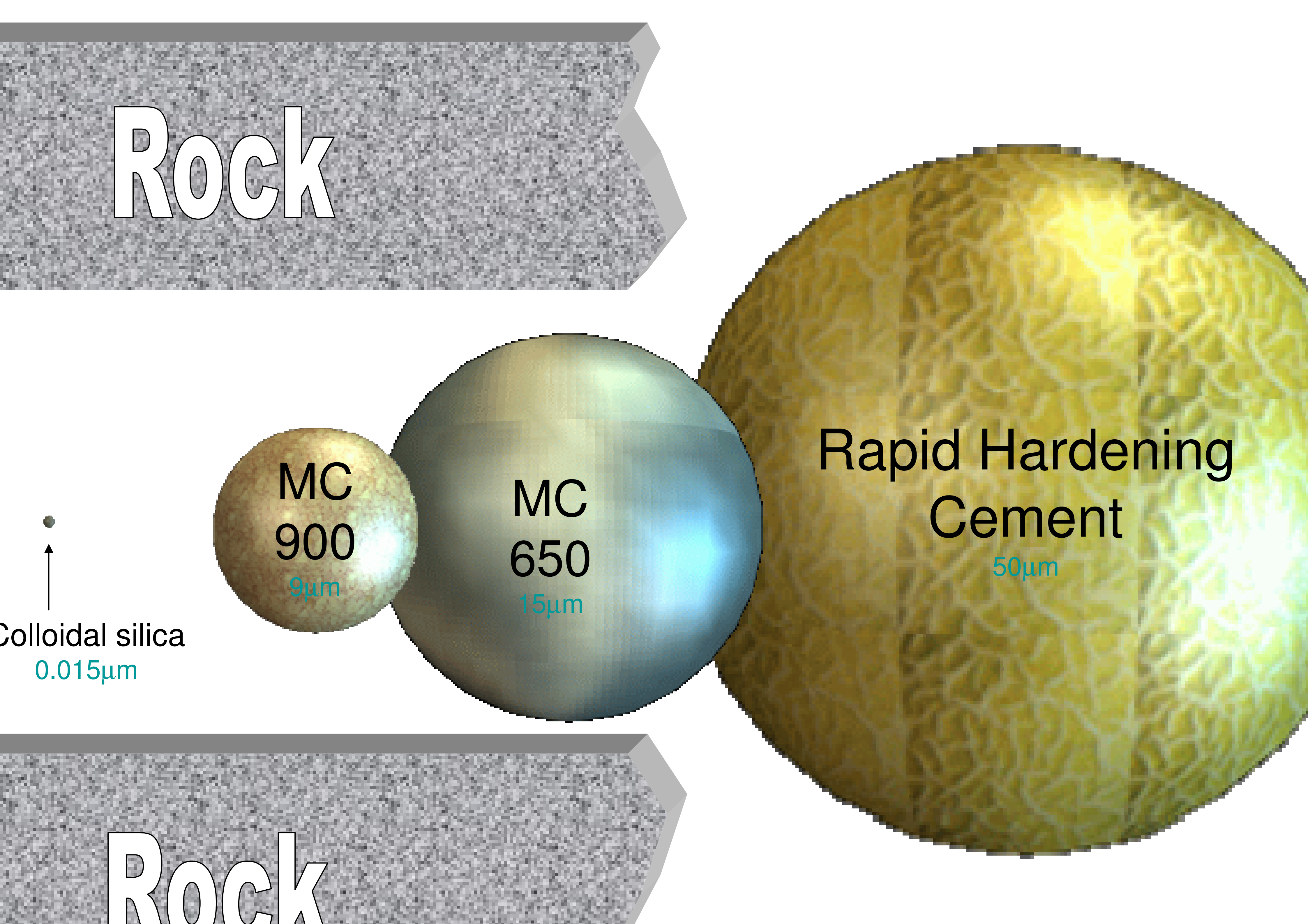
Single component cement grouting equipment

The accelerator is added to component A at the required ratio, and fully pre-mixed prior to pumping

The mixture of colloidal silica and accelerator is pumped with a one component piston pump through an injection packer into the rock

It is also possible to use other type of pumps. “If they pum water, they also pump Colloidal silica”

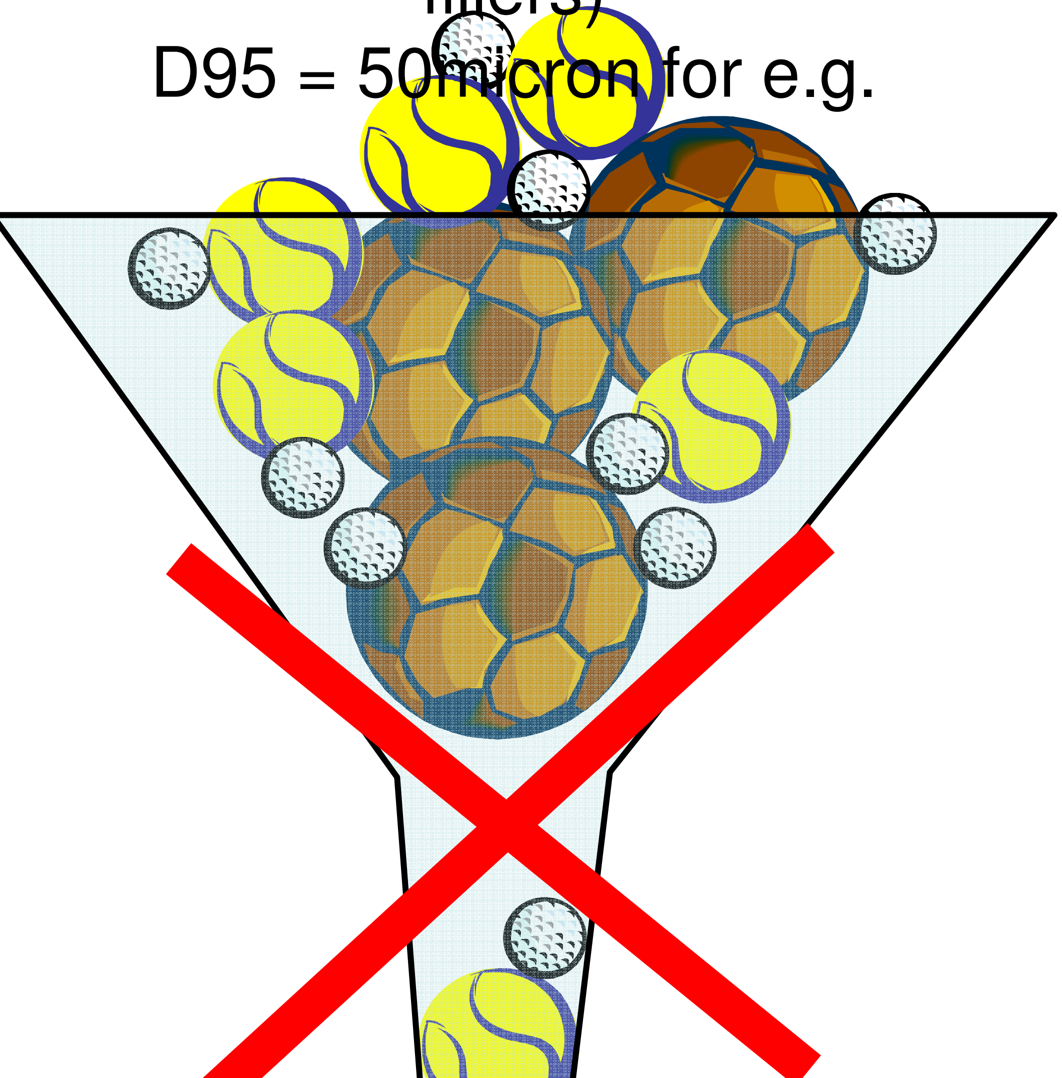
Easy cleaning: Water


Rock
MC
900
9µm
MC
650
15µm
Rapid Hardening
Cement
50µm
Colloidal silica
0.015µm
Rock

OPC cement

urface Area = High (if you add fine fillers)

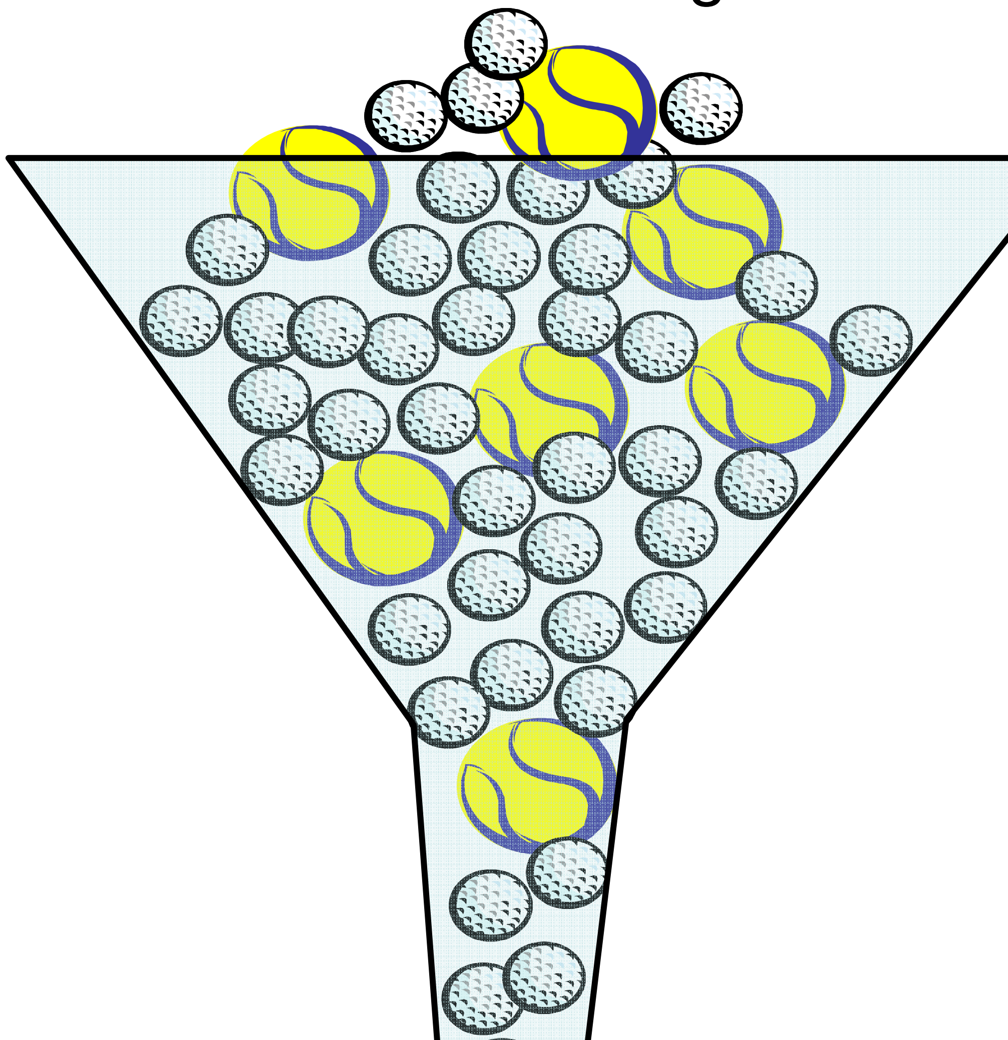
D95 = 50micron for e.g.



Microcement

Surface Area = High

D95 = 10micron for e.g.



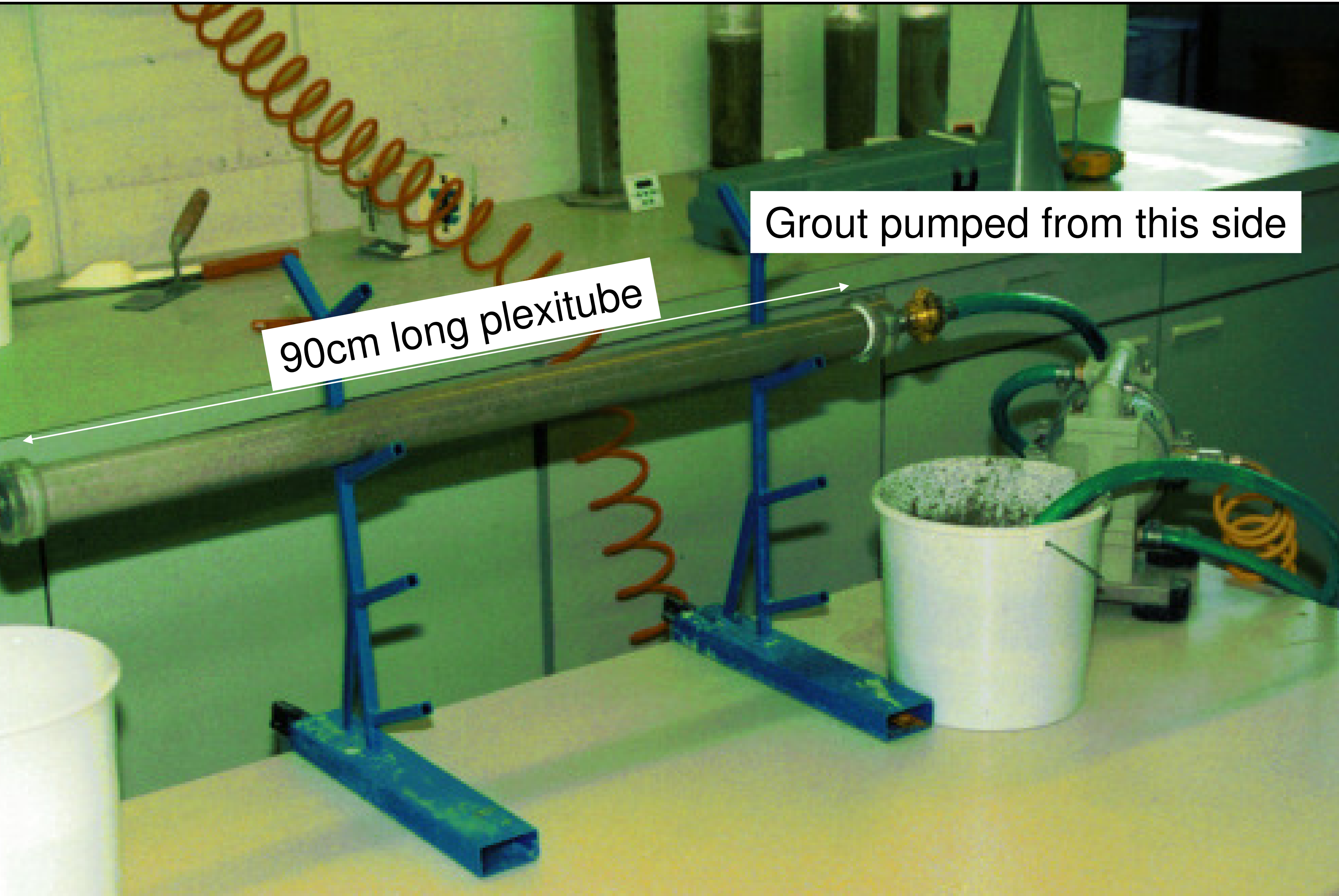
Water: 30 seconds

Micro cement 900 w/c = 1.0

Plasticiser 2%

Runs through in 33 sec.

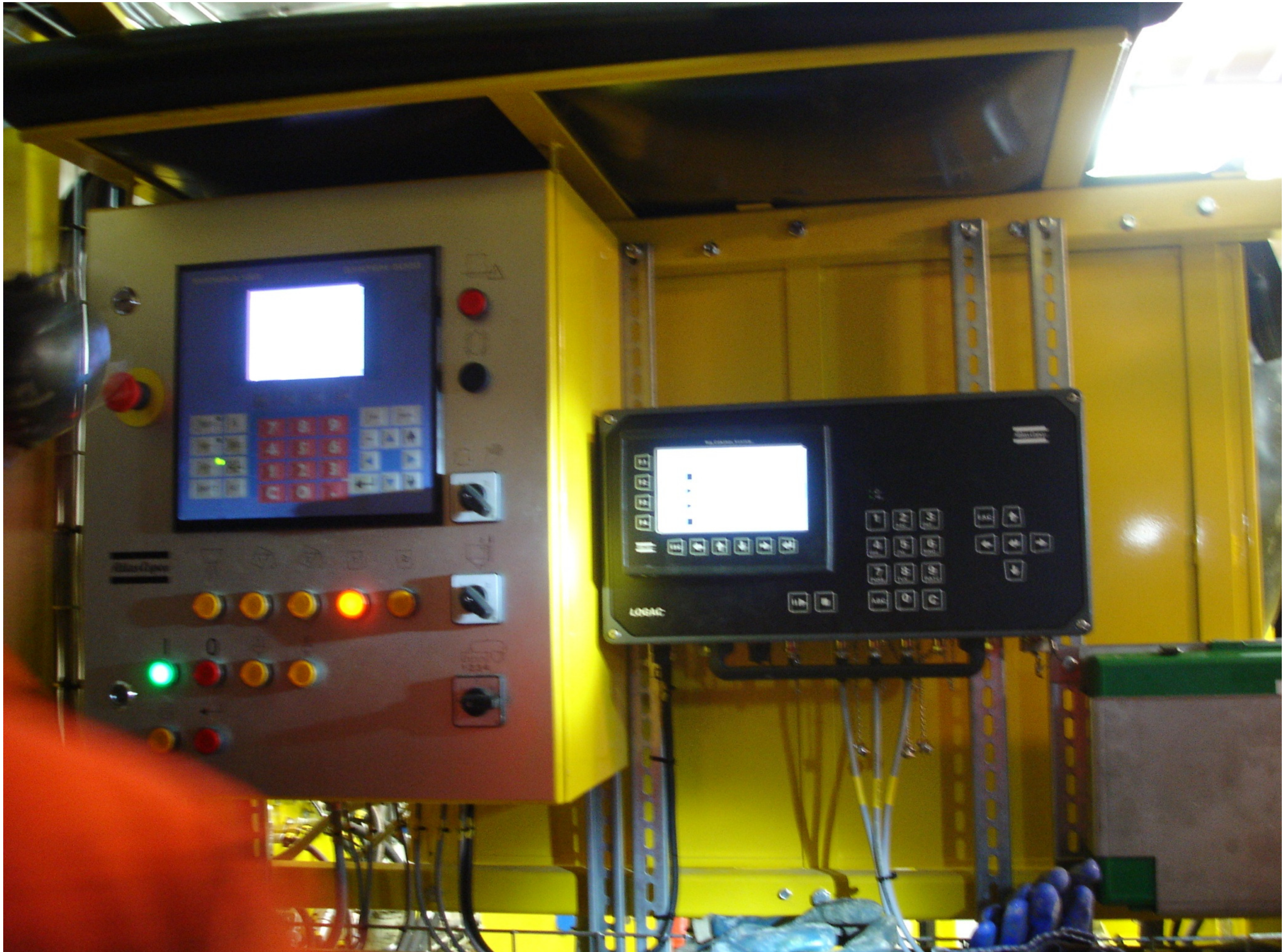
Penetration test for cement



plant, design by AMV, Norway


CEMIX

ocess with recording of all
arameters



Asker – Jong", Norway
Double track rail tunnel

- D&B tunnel 110
  ~ 7200 m
- Maximum allowe
  leak: 10 - 4
  l/min/100
- Systematically p
  injection with mi
  cement 800 and
  Rapid Hardening
- Achieved: Avera
  less than 2
  l/min/100m tunn

opane cavern, Mongstad" storage, Norway

y using pre injection it become totally light and dry "

plant - Oslo

Caverns: 136.000 m3 rock

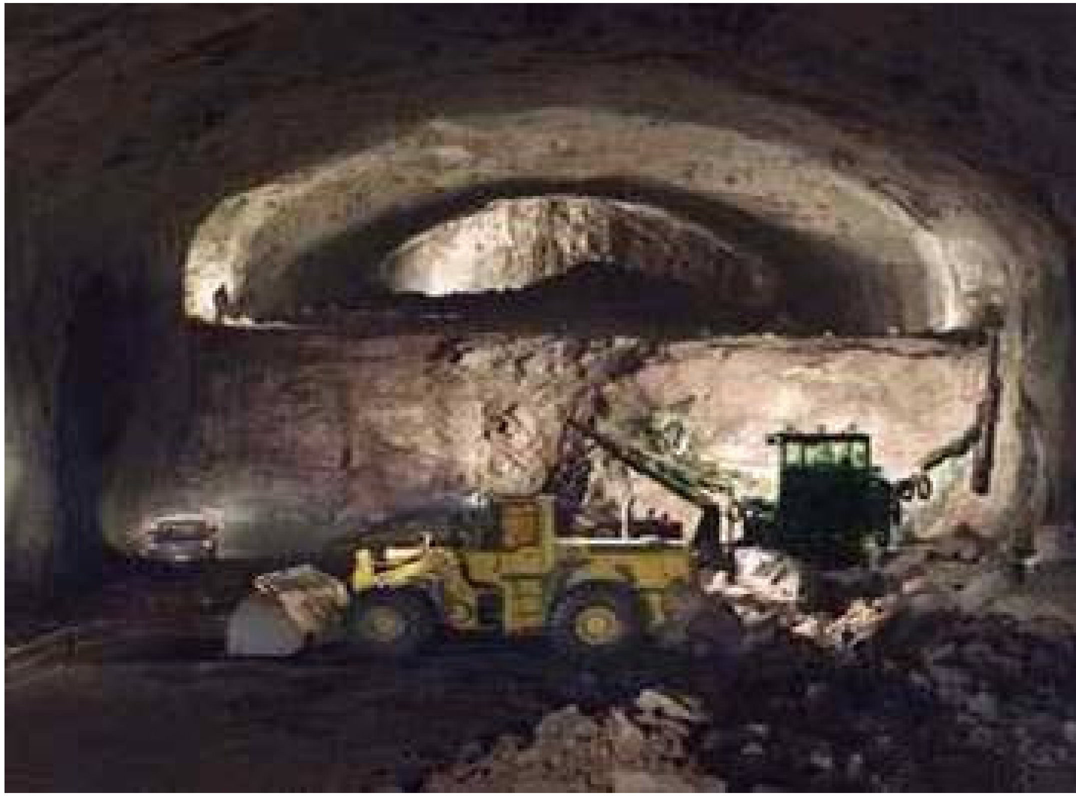
llowed inn leakage: 100 l/min

esult: 20 l/min

onsumption of injection
naterials:

ocal OPC: 820 tons

licro cement 650: 1510 tons



Approx 20 km TBM tunnels in hard rock at approx 4 m diameter under the city of Hong Kong.

The project was exposed to major “obstacles” due to water ingress

A regime utilizing pre-injection was implemented.

Total consumption of micro cement in all three contracts was > 5000 tons

The project was successfully completed with very limited

Norwegian grout advisor in action

Storage caverns underground in the Bukit Timah rock formation

Traditional D&B excavation method employed

Dry storage conditions required in the caverns

Pre-injection procedures implemented

Use of limited volumes of micro cement was implemented to meet the requirements

Norwegians above Bukit Timah caverns.

www.woldmo.com

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Management ▪ Equipment ▪ Materials