MEYCO Underground Construction

Sprayed Concrete - Basics

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MEYCO Global Underground Construction

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Introduction

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- Sprayed concrete was invented in 1907, and is today widely used for rock support world wide, both in mining and tunneling.
- For a long time dry mix application was the only way of applying sprayed concrete, but in the late seventies the wet mix method was introduced.

- The development in sprayed concrete has a long way since 1907, both in terms of equipment and concrete technology.

  Especially since the wet mix method started to get implemented, large technology steps have taken place.

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Introduction
Dry-mix method

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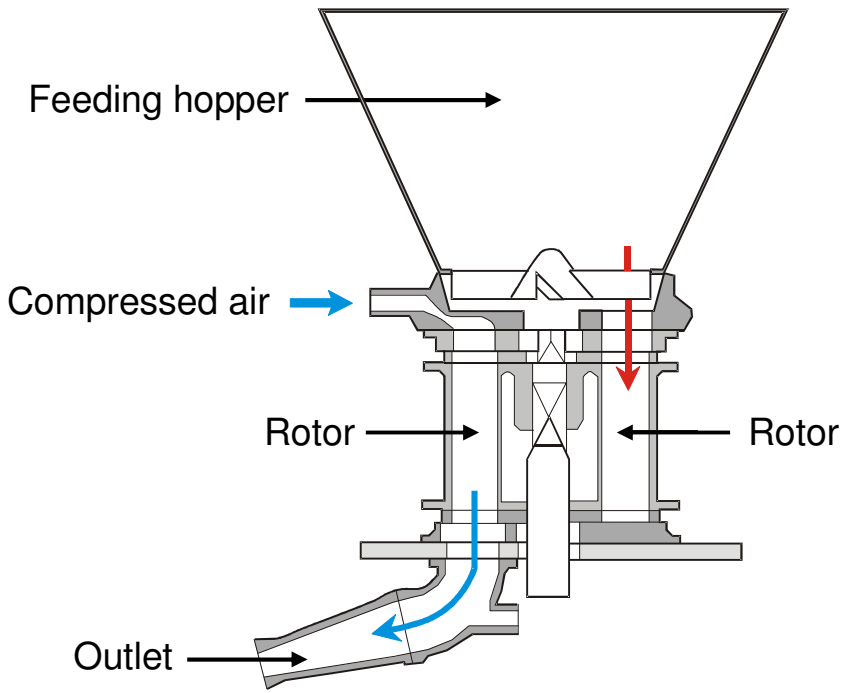
The rotor principle of a typical dry-spraying machine



- In the dry mix method, a premix of sand and cement is fed into the hopper of a machine that with the help of compressed air convey the mix through the hose to the nozzle where water is added.

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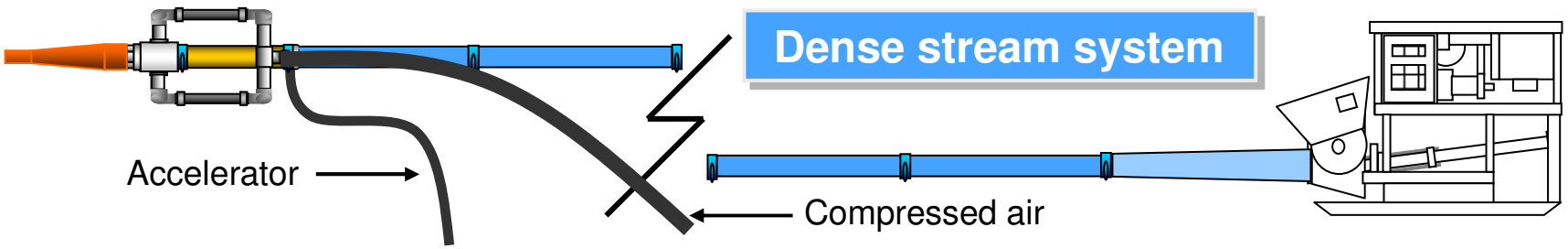
Introduction
Wet-mix method

- For the wet mix method, aggregate, cement, water and admixture are premixed in a concrete plant.
- Application of wet mix Sprayed Concrete is mainly performed by the use of piston pumps, that convey the concrete through the hosing system, and at the nozzle a set accelerator and air is added.
- The main benefit with the wet mix method versus the dry is; improved quality, less dust/improved working environment, less rebound, higher capacity and improved safety.



Introduction
Mix design dry-mix versus wet-mix

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Dry-mix

Cement CEM I		480 kg/m³
Sand	0/4 mm	1’200 kg/m³
Aggregates	4/8 mm	600 kg/m³
Water		added at the nozzle

Wet-mix

Cement CEM II A-LL		450 kg/m³
Sand	0/4 mm	1’200 kg/m³
Aggregates	4/8 mm	600 kg/m³
Water		200 kg/m³
Plasticizer		6 kg/m³
Retarder		2 kg/m³

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Introduction
EN standards for concrete

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EN 197	**Cement** Composition, specifications and conformity criteria
EN 206	**Concrete** Performance, production, placing and compliance criteria
EN 1008	**Mixing water for concrete**
EN 934- 2	**Admixtures for concrete, mortars and grouts** Part 2: Concrete admixtures
EN 934- 6	**Admixtures for concrete, mortars and grouts** Part 6: Sampling, quality control, evaluation of conformity and marking and labeling

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Introduction
EN standards for Sprayed concrete

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EN 934- 5	**Admixtures for concrete, mortars and grouts** Part 5: Sprayed concrete admixtures
EN 14487- 1	**Sprayed concrete** Part 1: Definitions, specifications and conformity
EN 14487- 2	**Sprayed concrete** Part 2: Execution
EN 14488- 1	**Testing sprayed concrete** Part 1: Sampling fresh and hardened concrete
EN 14488- 2	**Testing sprayed concrete** Part 2: Compressive strength of young sprayed concrete

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Introduction
EN standards for Sprayed concrete

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EN 14488- 3	**Testing sprayed concrete** Part 3: Flexural strength (first peak, ultimate and residual) of fibre reinforced beam specimens
EN 14487- 4	**Testing sprayed concrete** Part 4: Bond strength of cores by direct tension
EN 14487- 5	**Testing sprayed concrete** Part 5: Determination of energy absorption capacity of fibre reinforced slab specimens
EN 14487- 6	**Testing sprayed concrete** Part 6: Thickness of concrete on a substrate

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Introduction
EN standards for Sprayed concrete

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EN 14487- 7	**Testing sprayed concrete** Part 7: Fibre content of fibre reinforced concrete
EN 14889- 1	**Fibers for concrete** Part 1: Steel fibers
EN 14889- 2	**Fibers for concrete** Part 2: Polymer fibers

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Factors of influence on the quality Cement

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- CEM I is hard to find while a few years ago it was quite common.
- CEM II and III are most popular now but they are not as reactive.
- The replacement of cement with limestone, fly ash, silica fume and slag do not react with set accelerators and plasticizers.
- It's more difficult to achieve the required high early strengths for the accelerator and plasticizer.

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Factors of influence on the quality Aggregates

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- Water demand
- Workability
- Rebound
- Durability
- Shrinkage

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Factors of influence on the quality Water/Cement - Ratio

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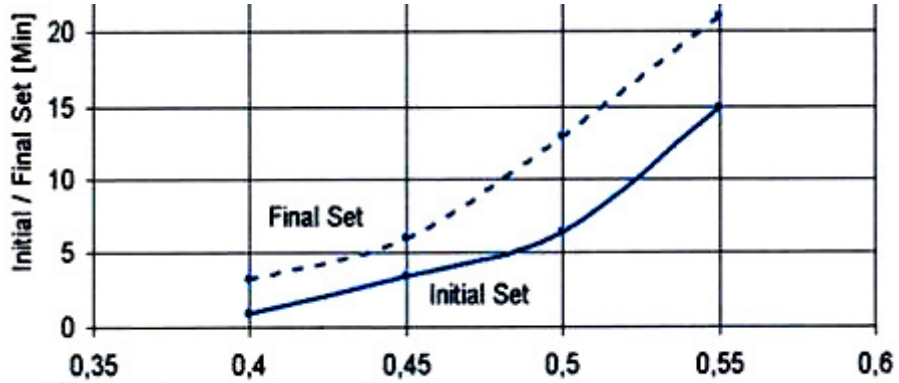
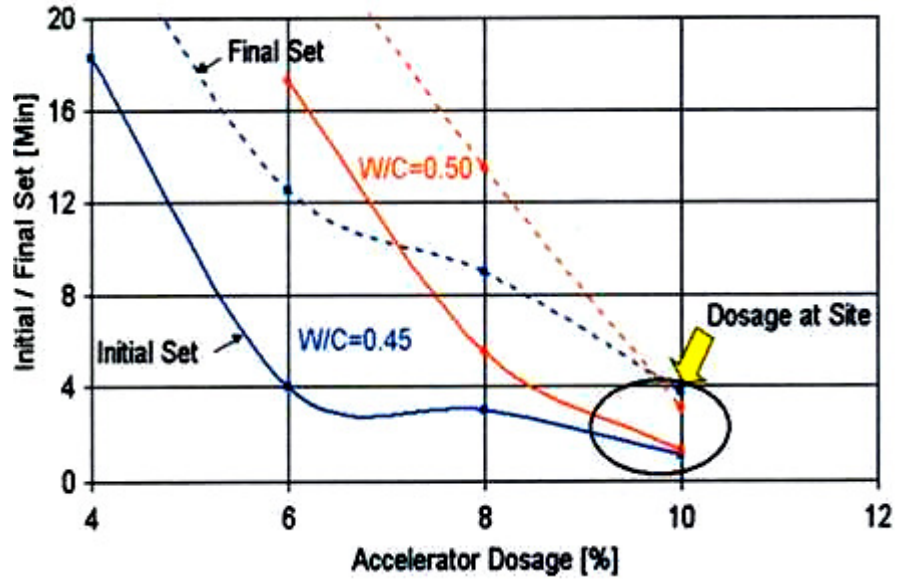
- **w/c – ratio is critical to:**
  - Early setting and strength development
  - Long term strength
  - Long term durability – resistance to chemical attack.
- w/c – ratio should be less then 0.50, preferably be around 0.45
- The use of high performance super plasticizers is recommended.





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Factors of influence on the quality Super Plasticizer GLENIUM®

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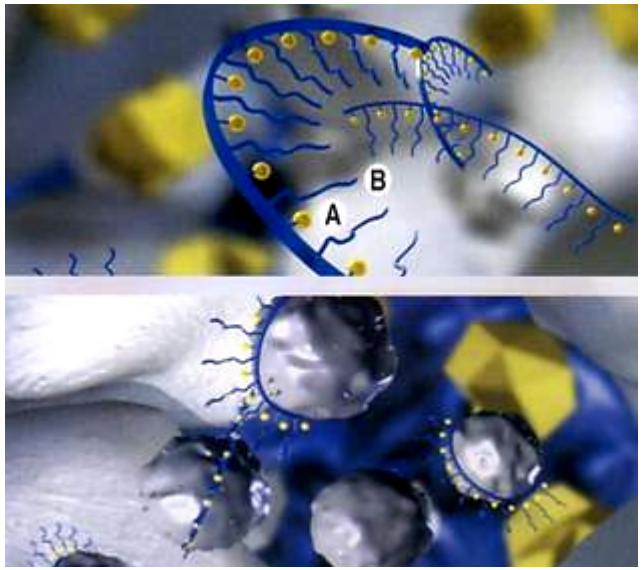

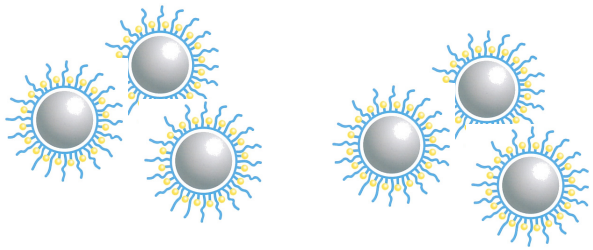

- Low water - cement ratio → 0.45
- High early and long term sprayed concrete strengths
- Pump able concrete mixes
- Durability enhancement
- Low dosage - cost effective

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Factors of influence on the quality
Admixtures for hydration control

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- Are usually added to sprayed concrete in order to maintain workability and extend the open time during transportation and application without reducing concrete quality.
- They can maintain workability, without influencing the hydration, from a few hours to three days depending on dosage rate .
- To reactivate and neutralize the hydration control effect, a sprayed concrete set accelerator is added during spraying.
- Hydration control admixtures have no negative influence on the accelerator dosage.
- The concrete mix can be reactivated at any time with the same accelerator dosage rate and with the same setting time, early and final strength development

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Factors of influence on the quality
Admixtures for hydration control

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Traditional sprayed concrete

NO CONTROL

Manufacturing — Delivery — Consumption

1 – 2 hours

Flexibility with DELVO® CRETE Stabilisator

TAKE BACK CONTROL

Manufacturing — Delivery — Intermediate storage — Consumption

3 – 72 hours

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Factors of influence on the quality Accelerator

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- Are added to the concrete during the spraying to increase the stiffening rate, to produce a fast ser and get sufficient early strength development.
- A fast setting concrete may be necessary to build up the lining at the required thickness and to ensure overhead security.

- Four different types of accelerator are available:
  - Alkali-free accelerators
  - Aluminates
  - Waterglass (Silicates)
  - Modified silicates

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Factors of influence on the quality Accelerator – pH scale

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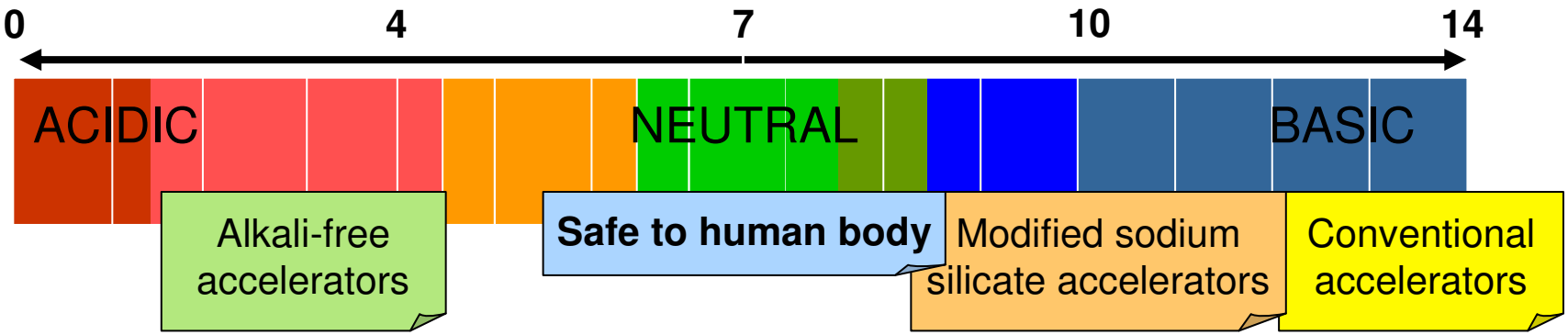

- Aluminates: high pH > 12 require particular care including personal protection against eye burns, skin burns and inhalation.
- Waterglass: pH > 12, the alkali content (Na_2O_{equiv}) between 10 & 18%.
- Modified silicates: pH < 11.5 and a low Na_2O_{equiv} < 8.5%
- Alkali-free: pH value between 2.5 and 8. The maximum Na_2O_{equiv} of the accelerator is limited to 1.0% by mass.

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Benefits Alkali-free accelerator over traditional accelerators

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Silicates

- Faster setting
- Faster strength developments
- Reduced loss of final strength
- Reduced permeability
- Better durability
- Reduced risk for AAR
- Better working environment and improved safety (less dust)
- Environment friendly

Aluminates

- Less sensitive to cements
- Dramatic reduction in loss of final strength
- Better durability
- Reduced risk for AAR
- Better working environment and improved safety
- Reduced permeability
- Environment friendly

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Alkali-free accelerators
Human and structure friendly

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- Improved working safety – no burns!
- Less dust and rebound
- Good short and long term strength
- Tick layer build rate
- Improved sulphate resistance when using standard cements
- Reduction of environmental impact in hardened state
- CREATES PERMAMENT STRUCTURAL CONCRETE

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Al_2O_3/SO_3 based set accelerator mode of action: Setting

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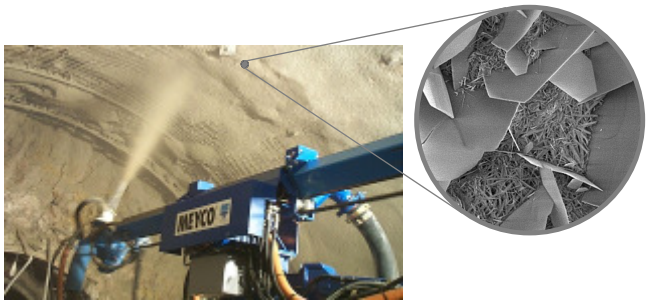
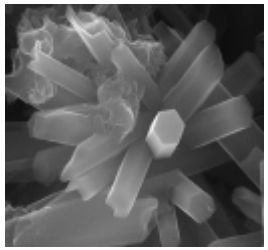
Cement Phase		Hydration Product	Reaction Rate	Contribution to Set	Contribution to Strength [*]
$2\mathbf{C_3S} + 7H$	→	$\mathbf{C_3S_2H_8} + 3CH$	moderate	High	High
$2\mathbf{C_2S} + 7H$	→	$\mathbf{C_3S_2H_8} + CH$	slow	Low	Low initially, high later
$\mathbf{C_3A} + 3C\hat{S}H_2 + 26H$	→	$\mathbf{C_6A\hat{S}_3H_{32}}$	fast	Very High	Low
$C_6A\hat{S}_3H_{32} + 2C_3A + 4H$	→	$3\mathbf{C_4A\hat{S}H_{12}}$			
$\mathbf{C_4AF} + 2CH + 14H$	→	$\mathbf{C_4(A,F)H_{13}} + \mathbf{(A,F)H_3}$	moderate	Moderate	Low

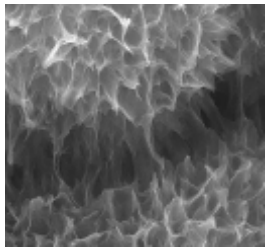
[*] H. F. W. Taylor. *Cement Chemistry*. London: Academic Press (1997), 113

The mechanism by which set accelerators achieve their effect is main fold :

- The increased dissolution of the clinker phases by the addition of set accelerators (pH < 3) benefits the quick setting.
- The components of these accelerators promote the precipitation of ettringite prisms at a very early stage.
- A rapid but non usual precipitation of C-S-H around the cement grains which enhances the early cohesion among the grains and other hydrates occurs. However, it has the strongly drawback to slow down the further dissolution of the anhydrous phases.







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Al_2O_3/SO_3 based set accelerator mode of action: Strength development

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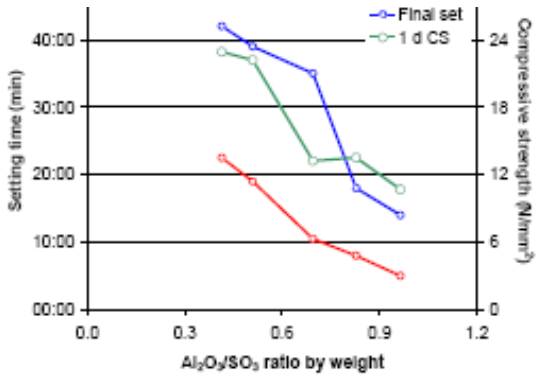
The fast setting caused by the addition of the set accelerator is related to a strengthened need on calcium ions in order to form a large amount of hydration products like ettringite, C-S-H…. It has been found that in the systems where the [Ca^{2+}] in the pore solution is low the growth of C-S-H is slowed down resulting in a poor strength development

The Ca ion concentration at times < 3 h is the key factor to control the strength development in accelerated systems because the anisotropic growth rates of C-S-H are controlled by the Ca ion concentration.

Fig. 4-31 Growth rates of C-S-H in (a) high Ca ion concentration (b) low Ca ion concentration

Fig. 4-32 Contact of silicate grains at (a) low Ca ion concentration (b) high Ca ion concentration

Al_2O_3/SO_3 ratio as well as the total amount of Al_2O_3 in the set accelerators influence the [Ca^{2+}] with respect to the precipitation of secondary gypsum which can redeliver Ca into the pore solution (in the case of MEYCO® SA160), and with respect to the formation of ettringite (in the case of MEYCO® SA180) which fixes Ca.



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Nozzle techniques have a marked effect on durability

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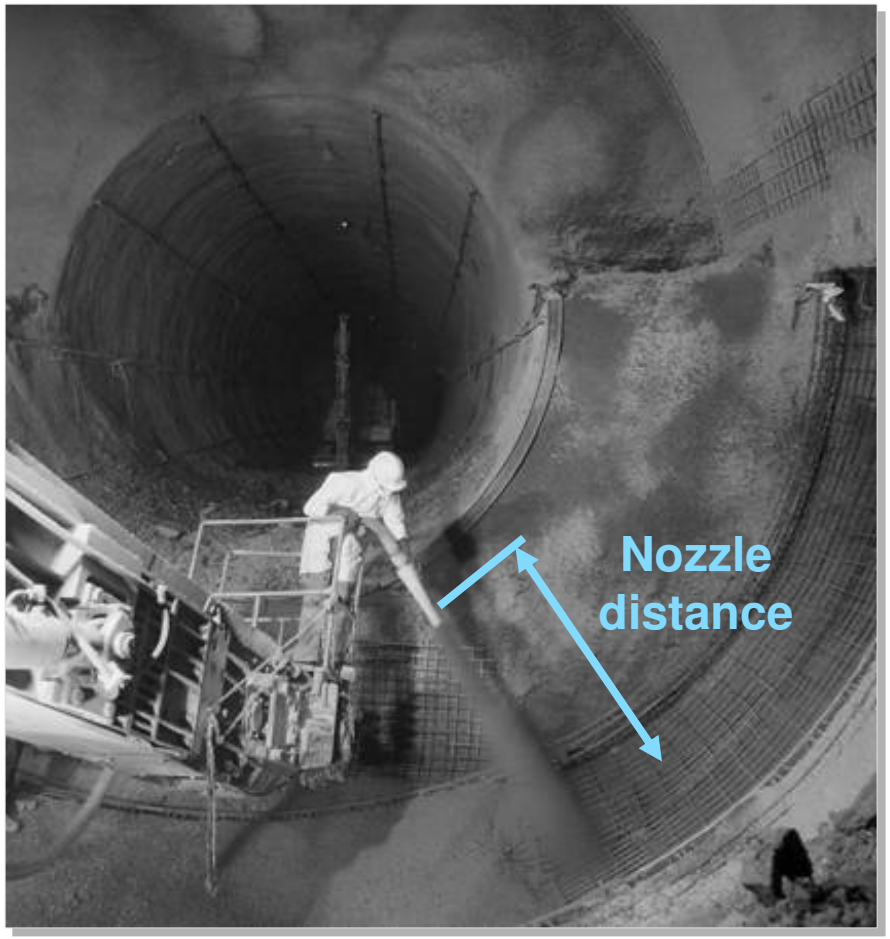

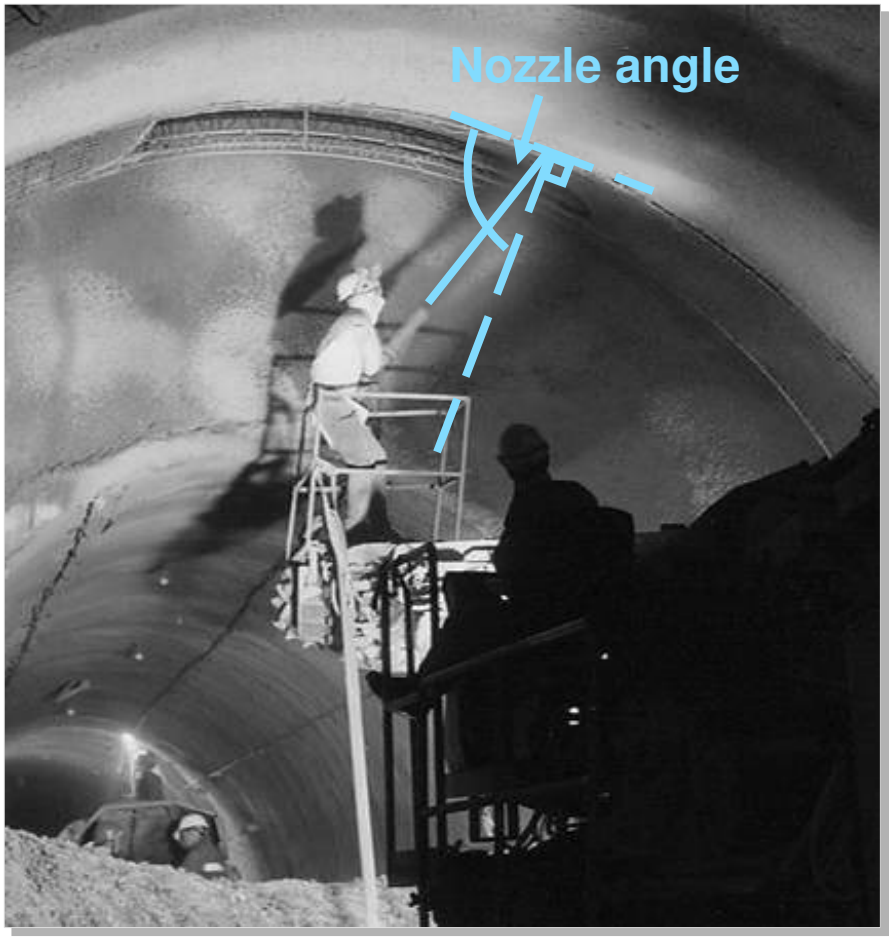

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Spraying operations
Nozzle system and set up

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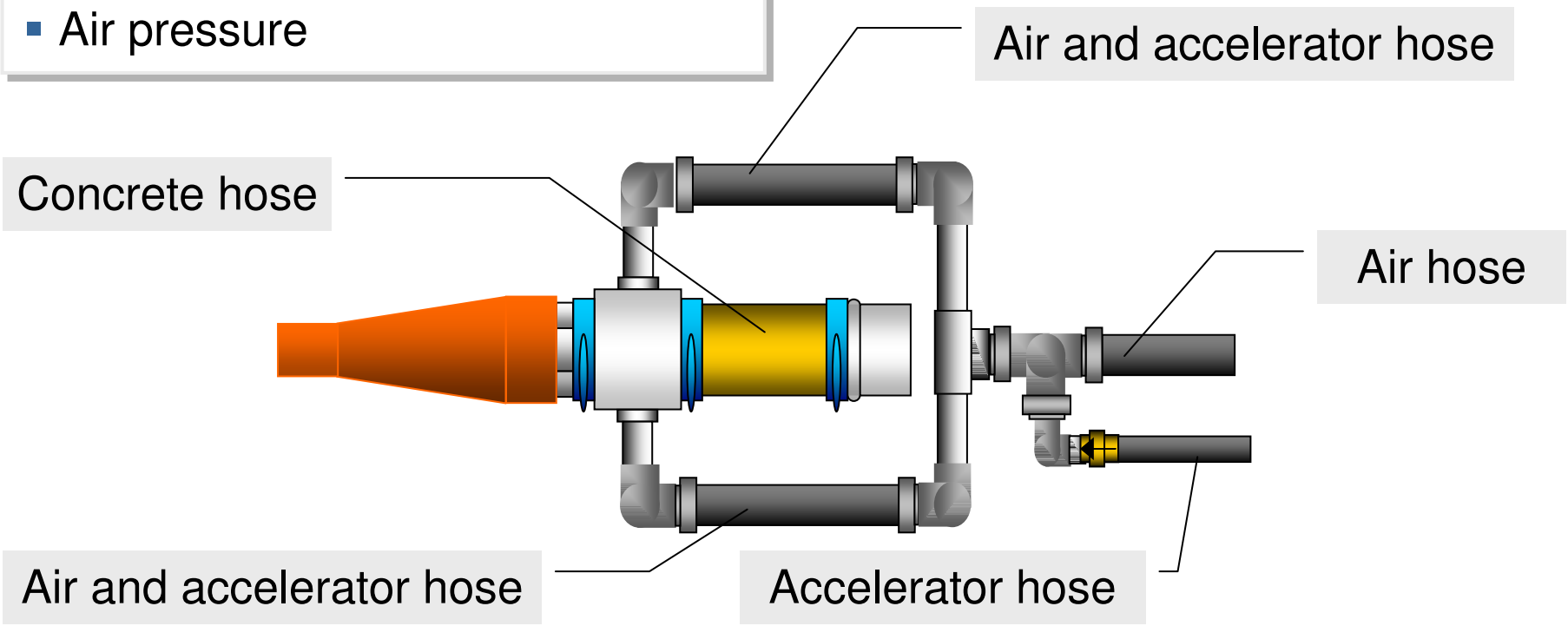
- Air and accelerator introduction
- Air volume
- Air pressure



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Pulsation
Interruption in the concrete flow/stream

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- **Pulsation is mainly caused be either one or a combination of the following two factors:**
  - Low workability (low slump) of the concrete to be sprayed.
  - The design/functionality of the equipment.

- **Some misunderstandings have led people to believe that:**
  - A low workability (low slump) concrete will require less accelerator
  - Have a positive effect in application of large total layer thickness
  - Is positive for setting, hardening and strength development

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Pulsation
Interruption in the concrete flow/stream

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This is not correct for the following reasons:

- To have an accelerator homogeneously mixed into the concrete stream is very important but extremely difficult in a low workability concrete (slump < 16 cm). The lower the workability is, the harder it is to have the accelerator homogeneously distributed into the concrete stream.
- Low workability leads to a reduced filling ratio of the concrete cylinders of the concrete pump. This creates pulsation in the concrete stream.

- Standard concrete pumps are designed to pump conventional concrete. Generally they give significantly higher pulsation than pumps designed specifically for Sprayed Concrete. Low workability concrete dramatically reinforces this effect.

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Pulsation
Interruption in the concrete flow/stream

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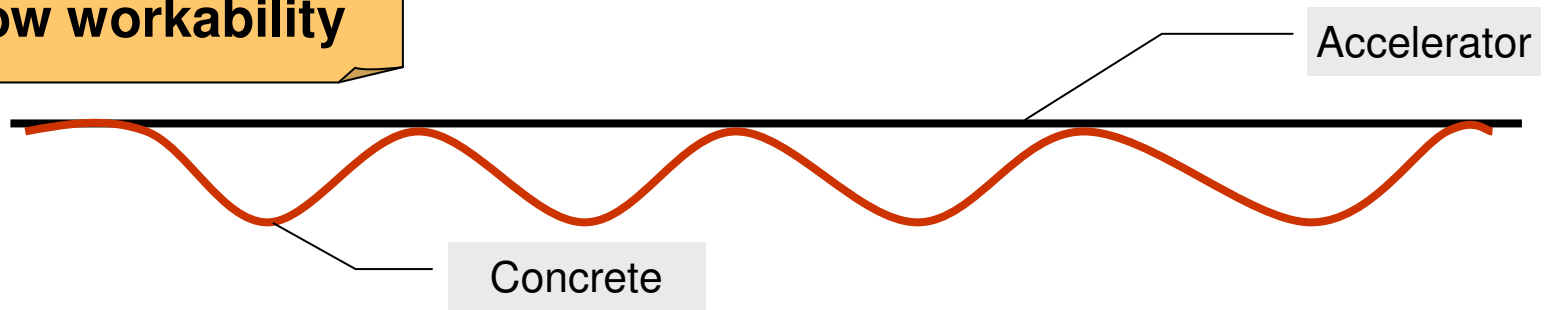
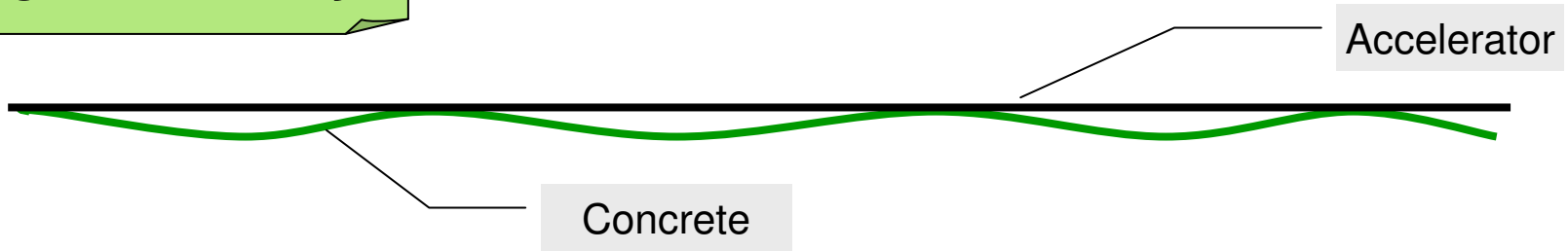
Low workability



Concrete output versus accelerator dosage

High workability



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Pulsation
Interruption in the concrete flow/stream

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Pulsation will result in

- Sagging and slip off/drop outs of concrete during application.
- Layering effect in the applied sprayed concrete.
- Reduced durability due to the negative effect of the Sprayed Concrete from over-dosage of accelerator.
- Reduced strength and safety, due to the entire thickness not acting as one uniform layer.

Layering

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Parameter effecting mixing and performance of accelerator

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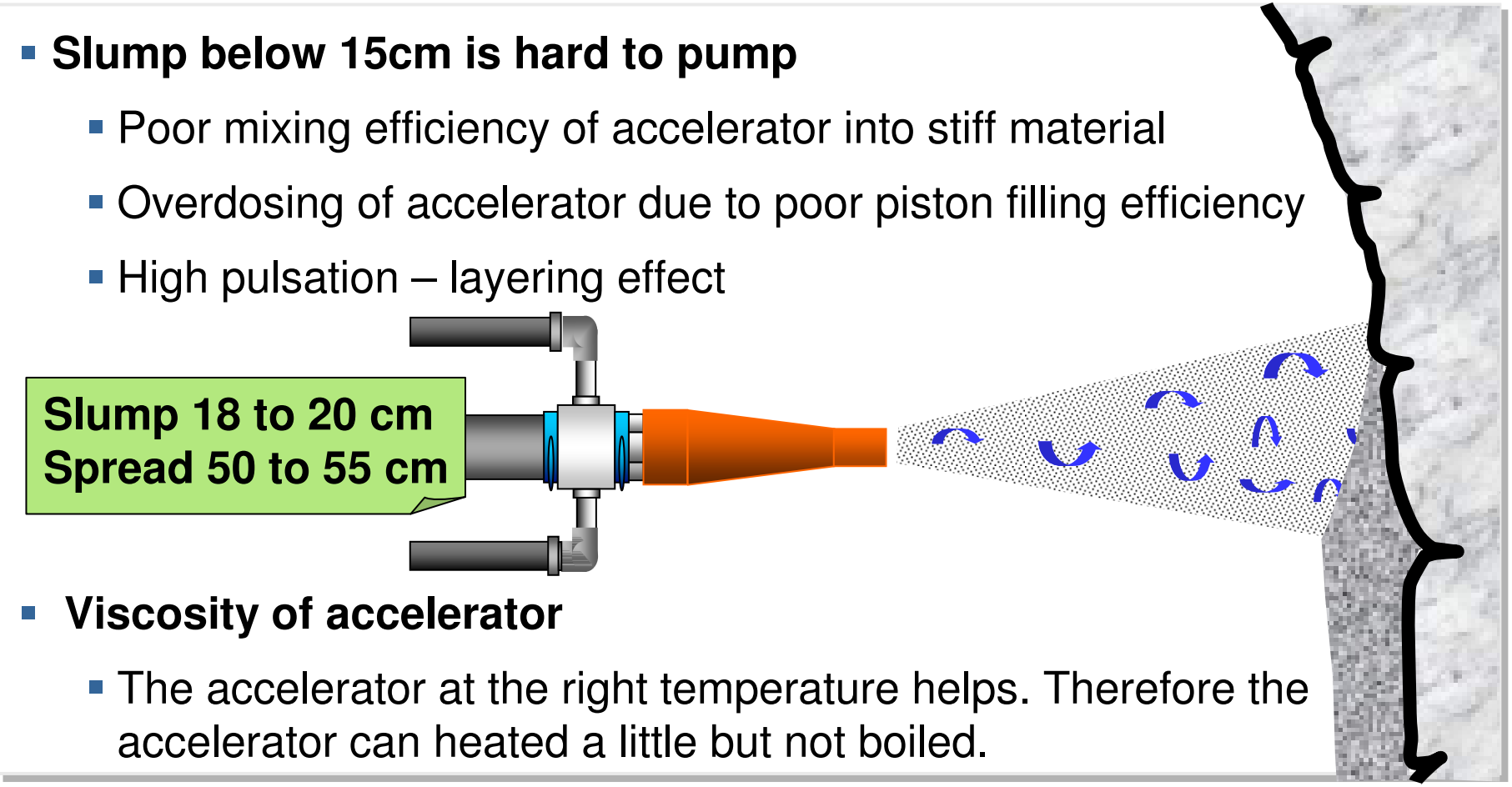
- **Slump below 15cm is hard to pump**
  - Poor mixing efficiency of accelerator into stiff material
  - Overdosing of accelerator due to poor piston filling efficiency
  - High pulsation – layering effect



- **Viscosity of accelerator**
  - The accelerator at the right temperature helps. Therefore the accelerator can heated a little but not boiled.

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Sprayed concrete
Early strength development

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- The terminology, early strength is mostly used for the strength developed from time of application until the first hour is reached.
- This early strength is critical for the application, in terms of being able to build a Sprayed Concrete layer without sagging and drop outs →3 & 6 minutes.
- But, there is a link between very early strength and strength development.
- Too high early strength very often results in a lower strength development.

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Sprayed concrete
Early strength development

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- The early strength is most essential as mentioned for the application
- Safe application without drop outs at an effective speed of application to the required thickness must be ensured
- Temperature of concrete, ambient temperature as well as the temperature of the strata, and the applied thickness is a very important factor for initial and final set, as well as further strength development

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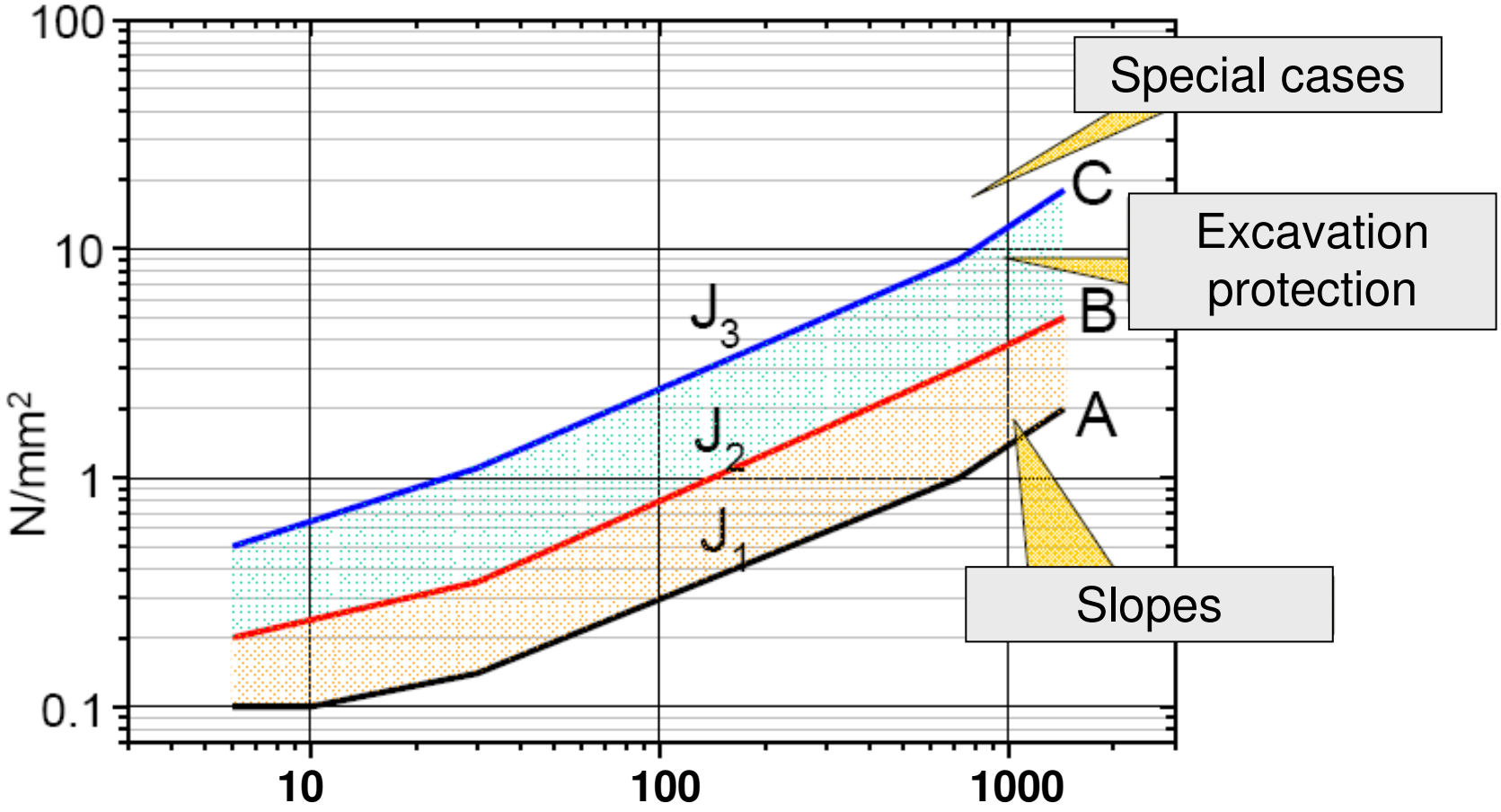
Sprayed concrete
Strength development



Sprayed concrete
Strength development

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- Continue with strength measurement → Hilti Equipment

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Accelerator
Setting and strength development

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- The accelerators initially act as a slump killer, and immediately reduce the workability of the Sprayed Concrete to a zero slump.

- The sprayed concrete is still in a plastic state at the time it reaches the substrate.

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Sprayed concrete
Mid term strength & final strength

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- Mid term strength is mostly meant for the **7 days**, but often civil projects can have a requirement for 3 days strength.

- Final strength is mostly used for **28 days** strength.

- But with some of the alkali-free accelerators, one can see a continuous strength development also after 28 days, in comparison to a decrease in strength over time, as has been the fact with traditional accelerators like Silicate and Aluminate based accelerators.

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Sprayed concrete Summary

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- W/C ratio to be controlled
- No retarding admixtures
- Good workability of the concrete to ensure a homogeneous mix of the accelerator into the concrete stream
- Minimize pulsation with choose of correct engineered equipment, and good workable concrete that allow for a high filling ratio
- Initial and final set to be balanced
- Temperatures and applied thicknesses influence strength development
- Control of strength development
- Curing conditions/after treatment of the concrete is essential for strength development and durability

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