11-19-2019

Investigations regarding the pumping process of wet-mix shotcrete improvement and upgrading of underground traffic structures

Johannes Flotzinger
University of Regensburg, Germany

Maria Thumann
OTH Regensburg, Germany, maria1.thumann@oth-regensburg.de

Florian Steindl
Graz University of Technology

Florian Mittermayr
Graz University of Technology

Benedikt Lindlar
Sika Services AG, Zürich

Authors

Johannes Flotzinger, Maria Thumann, Florian Steindl, Florian Mittermayr, Benedikt Lindlar, and Wolfgang Kusterle

Investigations regarding the pumping process of wet-mix shotcrete

Johannes Flotzinger, Maria Thumann, Prof. Wolfgang Kusterle
(OTH Regensburg)
Lukas Briendl, Florian Steindl, Florian Mittermayr
(Graz University of Technology),
Benedikt Lindlar
(Sika Services AG, Zürich)

Shotcrete for Underground Support XIV

Outline

1. ASSpC
2. Stability and rheology
3. Shotcrete rig and sensors
4. Results
5. Resume
6. Outlook

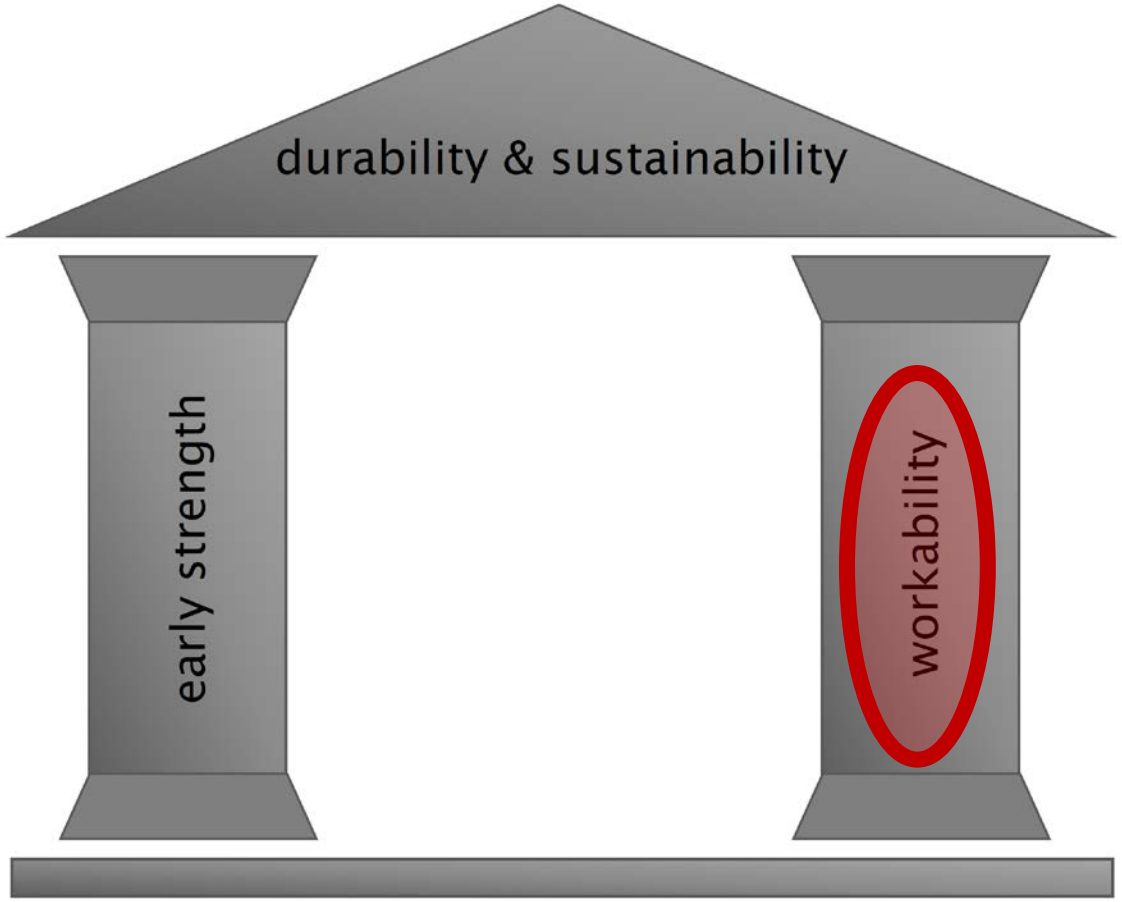
ASSpC (Advanced and Sustainable Sprayed Concrete)

- Increase of durability of construction/shotcrete
- Use of sustainable materials
- Reduction of environmental footprint

→Low maintenance costs

→Good life cycle performance

ASSpC



Goals

Fresh concrete tests:

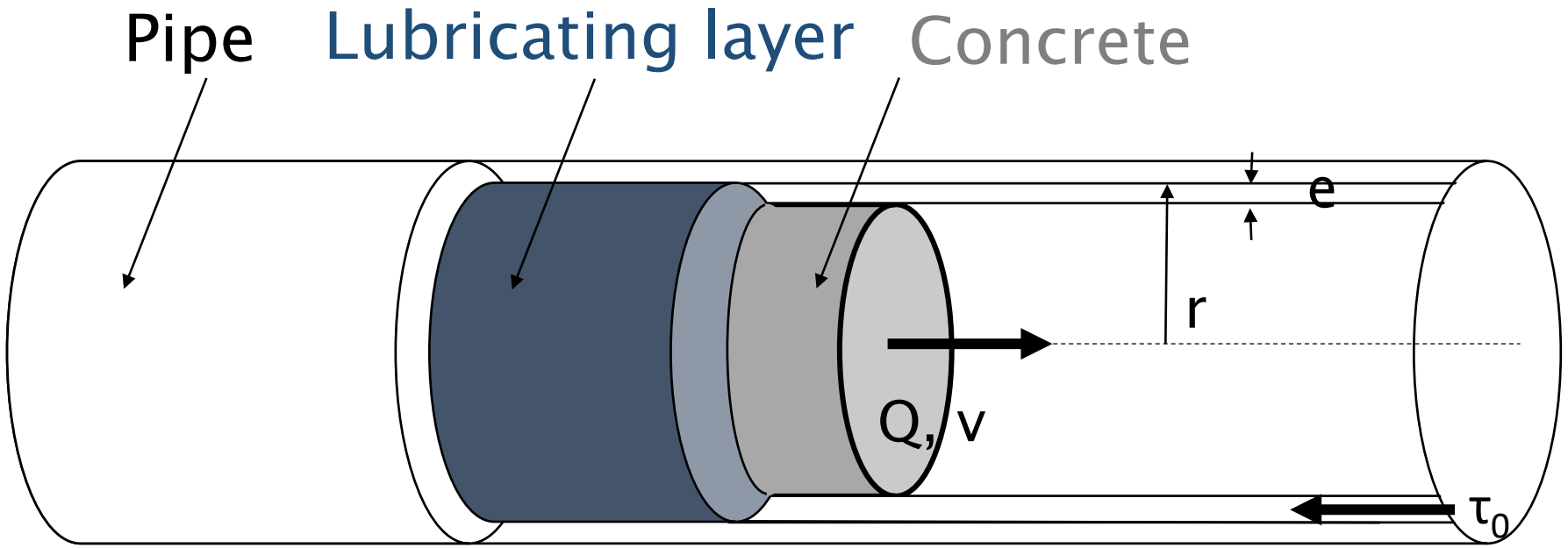
- What measurements can be made to determine the rheology and stability of the shotcrete?

Pressure tests:

- How do the flow rate and hence the pressures affect the quality of the spray pattern?

→ Can the pumping pressure be determinated before the spraying process by fresh concrete properties?

Schematic illustration

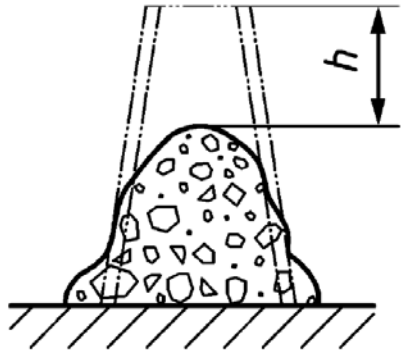


Source: Kasten, K.: Gleitrohr-Rheometer. Ein Verfahren zur Bestimmung der Fließeigenschaften von Dickstoffen in Rohrleitungen. Dissertation. Dresden 2009.

Experimental setup

Common tests for describing the fresh concrete properties:

- Flow table spread or slump flow
- The Austrian guideline for shotcrete recommends a flow spread of 600 ± 50 mm
- The segregation, the demand of water and the dosage of super-plasticiser must be taken into account
- Investigations of *Reinhold, Secrieru et al., Kasten, Jacobsen and Ngo* showed that flow spread and slump flow are insufficient for describing the pumpability of concrete



EN 12350-2:2019

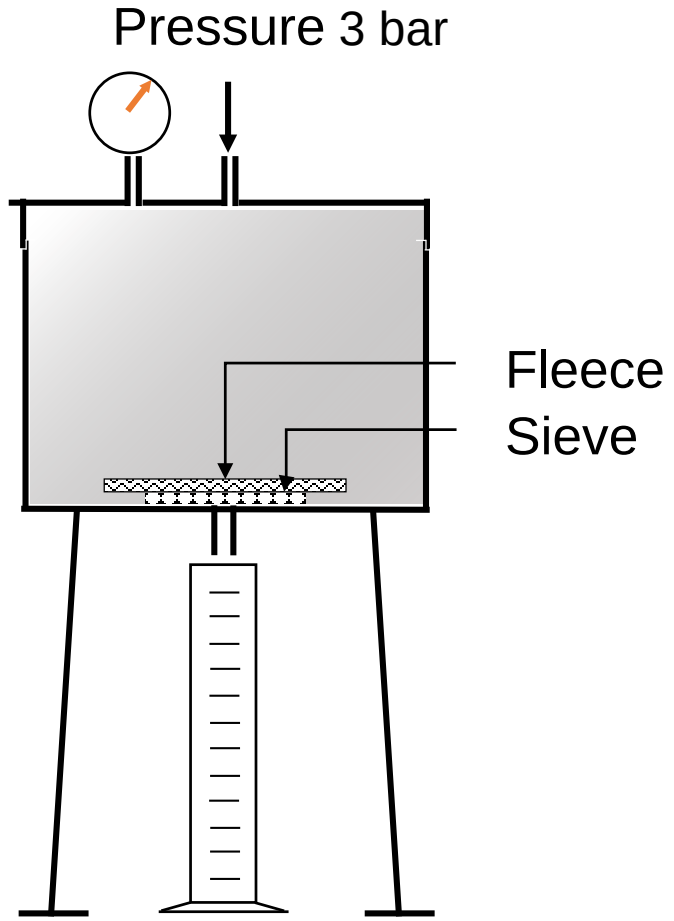
Test methods of the fresh concrete

Flow table spread

- Flow table spread
- Filter pressing test
- SLIPER (SLIding PipE Rheometer)

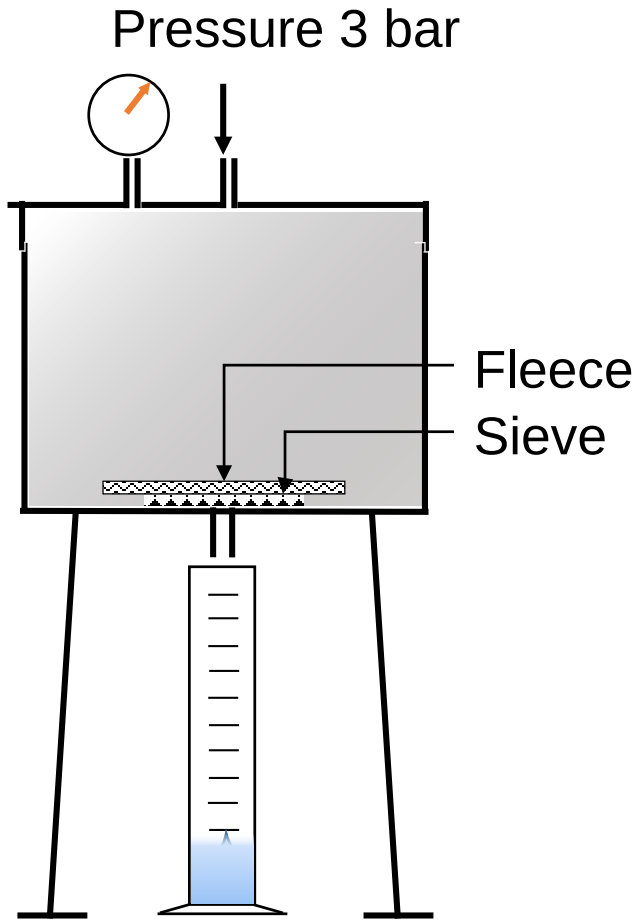
Stability

Filter press

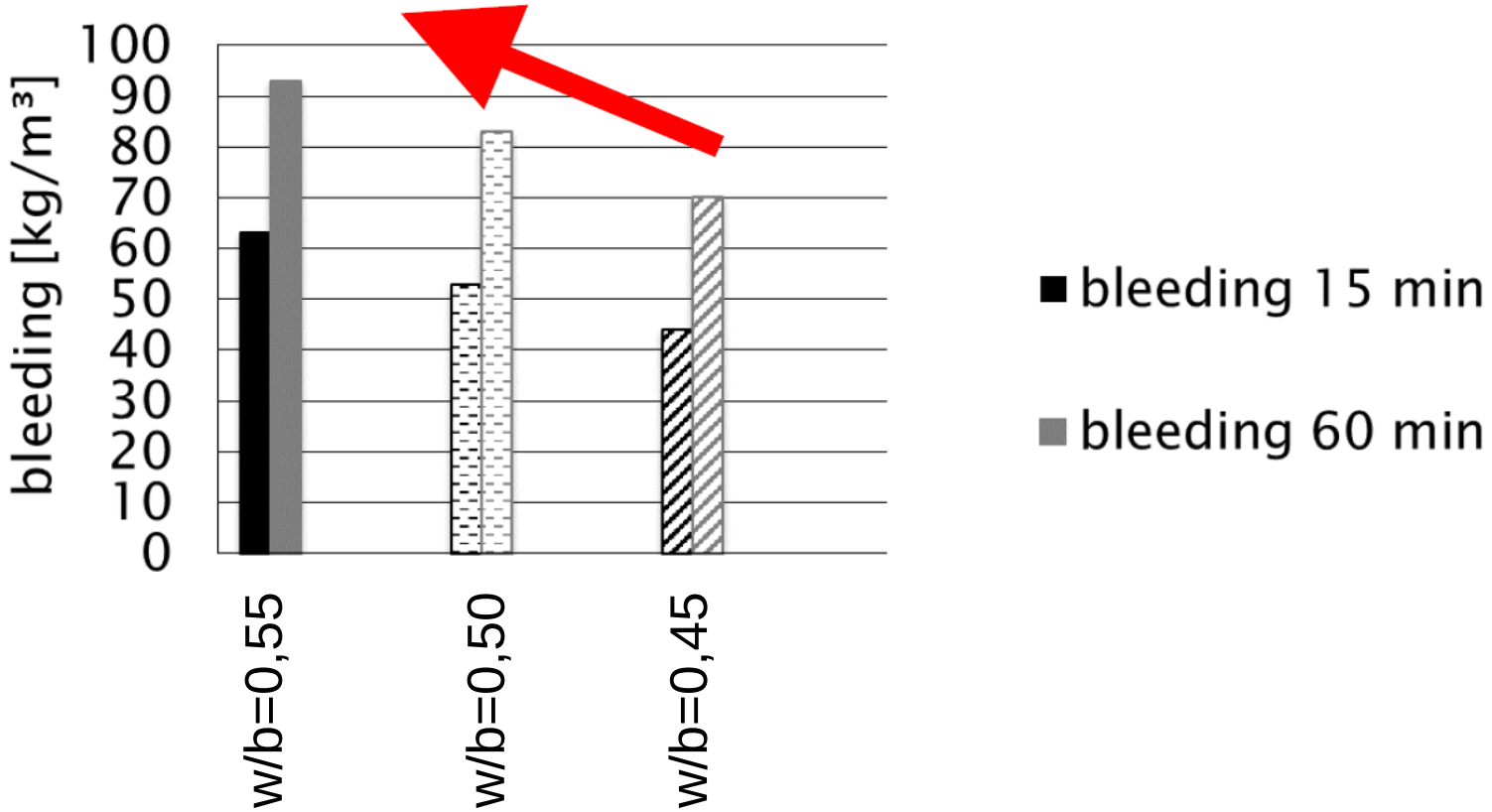


Stability

Filter press



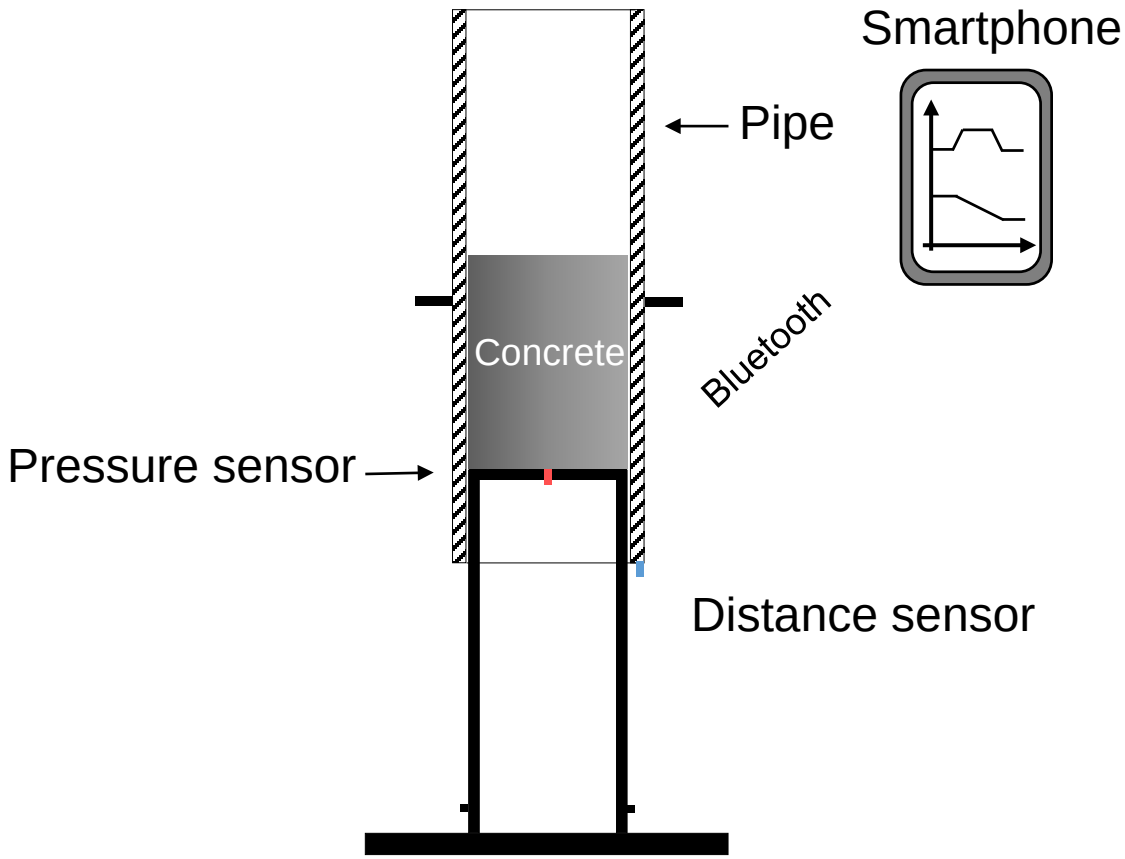
Stability



Filter press results at different w/b ratios

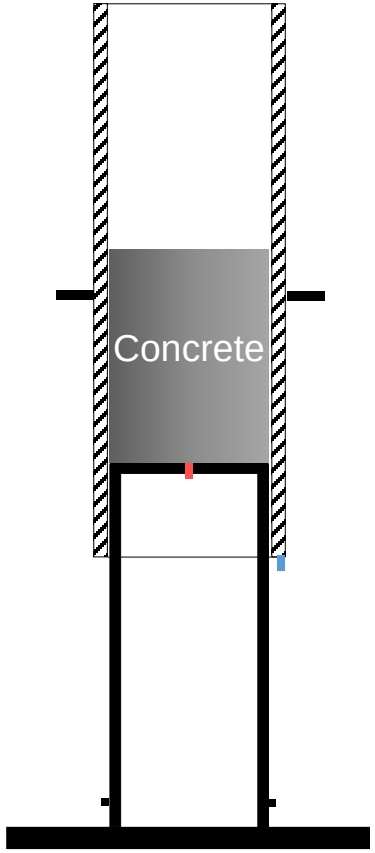
SLIPER (SLIding PipE Rheometer)

Sliper

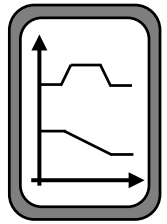


SLIPER (SLIding PipE Rheometer)

Sliper

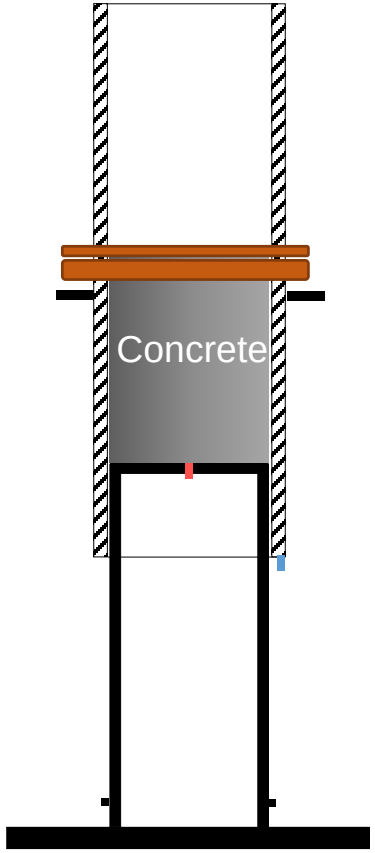


Smartphone

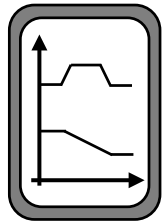


SLIPER (SLIding PipE Rheometer)

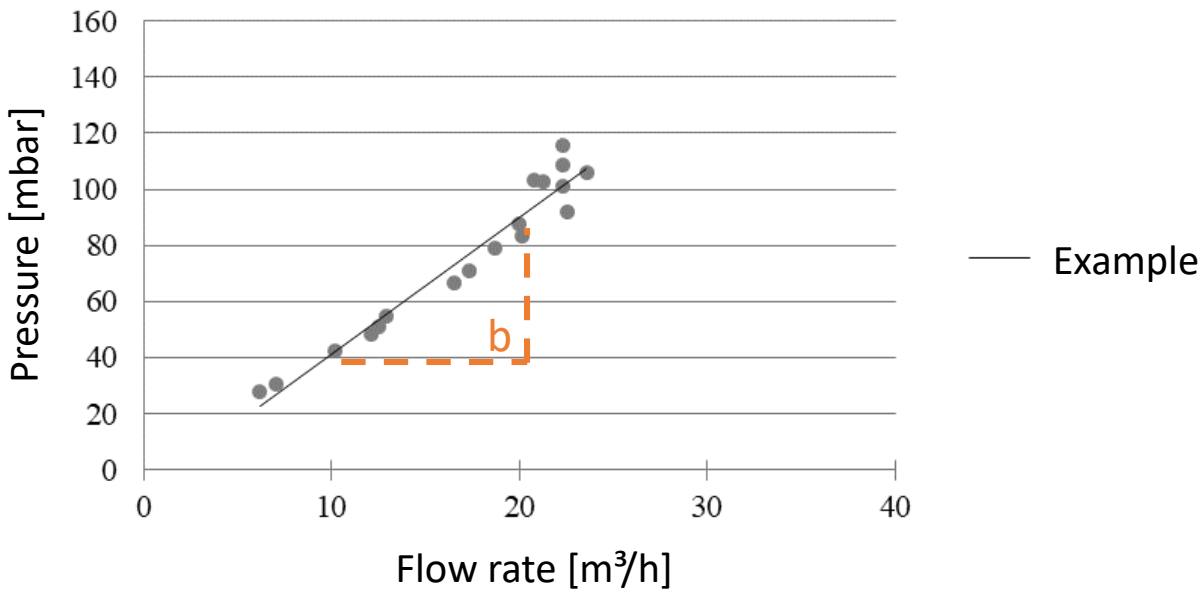
Sliper



Smartphone



Sliper measurement



- Y-axis: The maximum pressure
  - measured by the sensor
- X-axis: Flow rate
  - Velocity*Cross section
- Two parameters of the lubricant layer can be obtained:
  - a represents the „yield stress“
  - b represents the „viscosity“

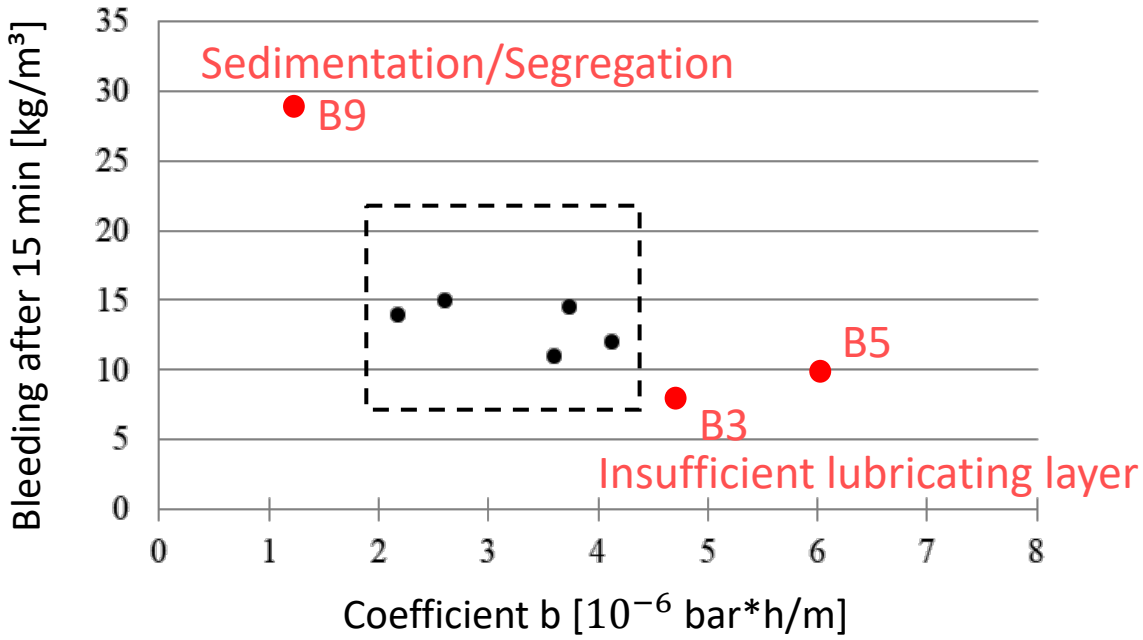
Formula for calculating the concrete pressure (p_s)

$$p_S = a \cdot 4 \cdot \frac{L_{\bar{a}}}{D} + b \cdot 16 \cdot Q \cdot \frac{L_{\ddot{a}}}{\pi \cdot D^3} + \rho \cdot g \cdot H$$

Depends on:

- a (Sliper-Yield stress)
- b (Sliper-Viscosity)
- Diameter of the pipe
- Flow rate
- Density of the concrete
- Delivery head (assumed 5m)

Stability and Rheology

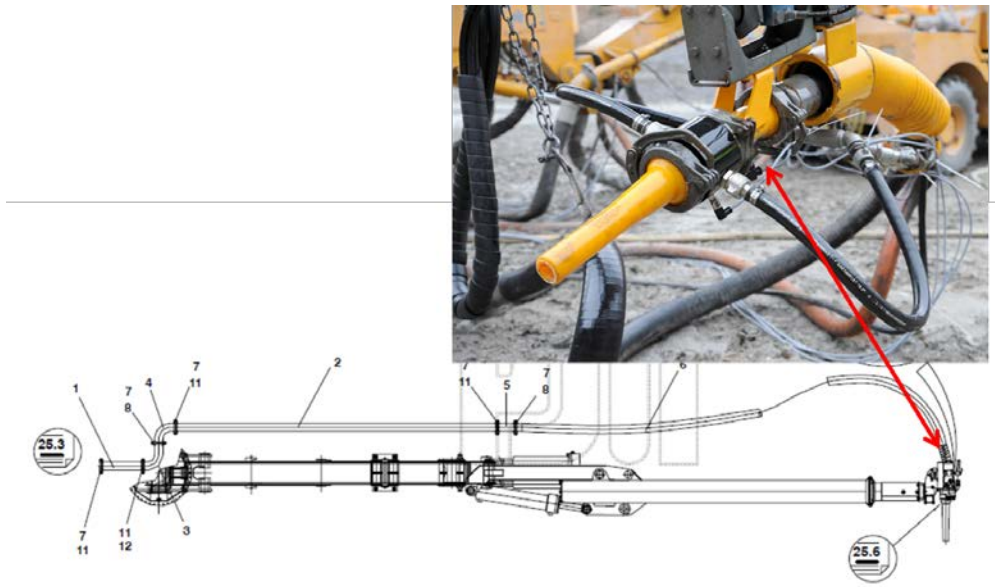


Shotcrete rig

Filling of the shotcrete pump

Checking the sensors

The sensors



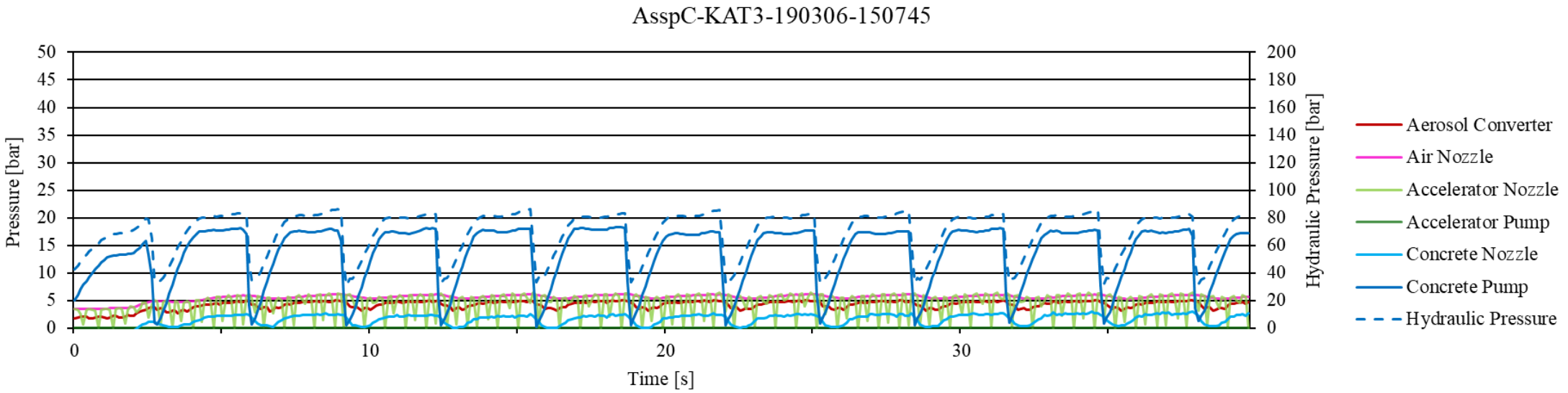
Sensors at the nozzle

Data logger

Results

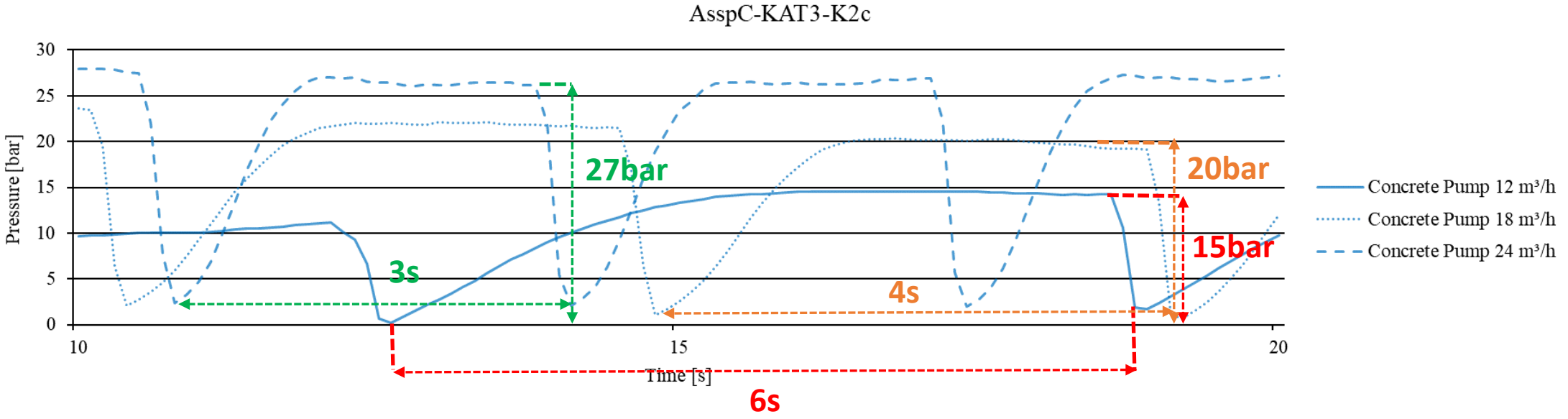
Mix-Design		**Reference**	**w/b-High**
w/b	[-]	0,47	**0,52**
Water	[dm³/m³]	189	204
Fines*	[dm³/m³]	170	159
Air void content (measured)	[dm³/m³]	8	10
Total paste volume	[dm³/m³]	367	373
*cement+aggregates < 0.125mm+additives			

Results



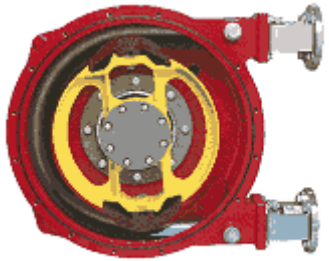
Pressures of all sensors during one Measurement (Reference)

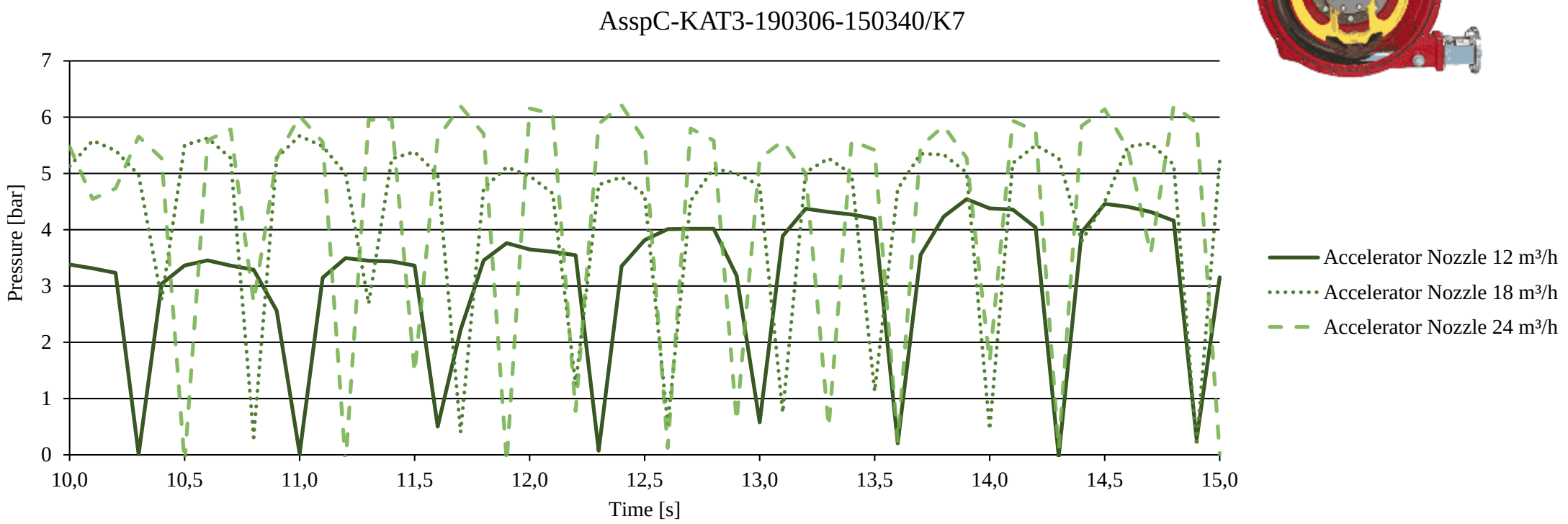
Results



Comparison of the concrete pump pressures at different flow rates but with the same mixture (Reference)

Results

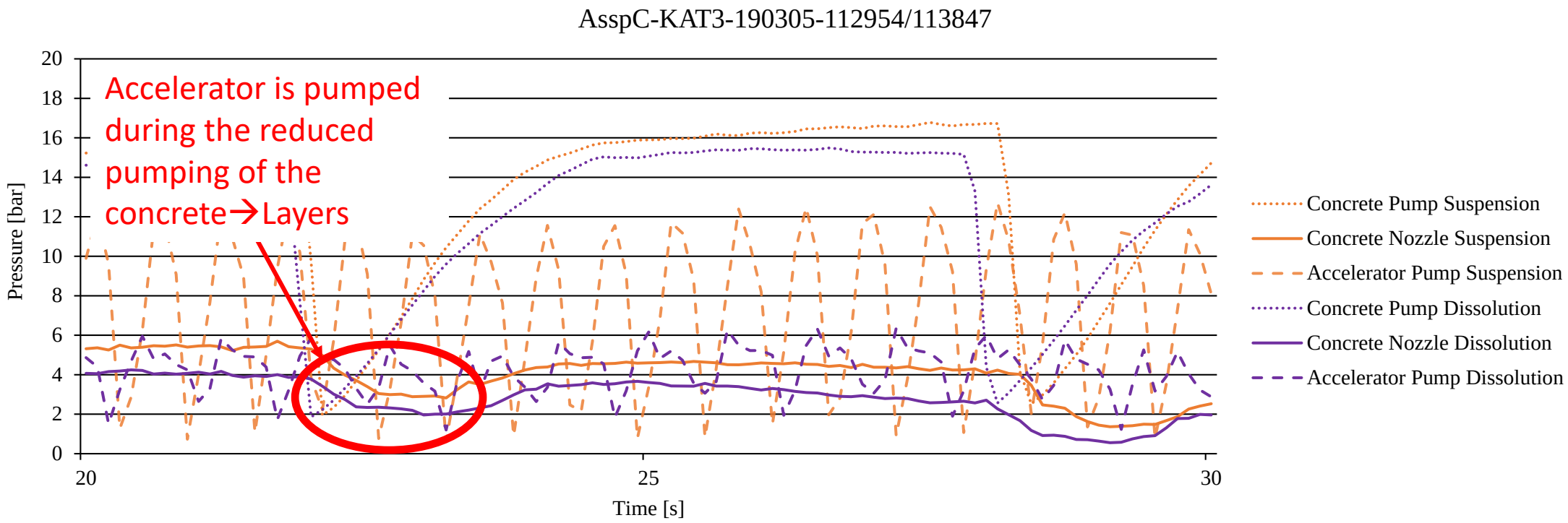




Comparison of the accelerator nozzle pressures at different flow rates

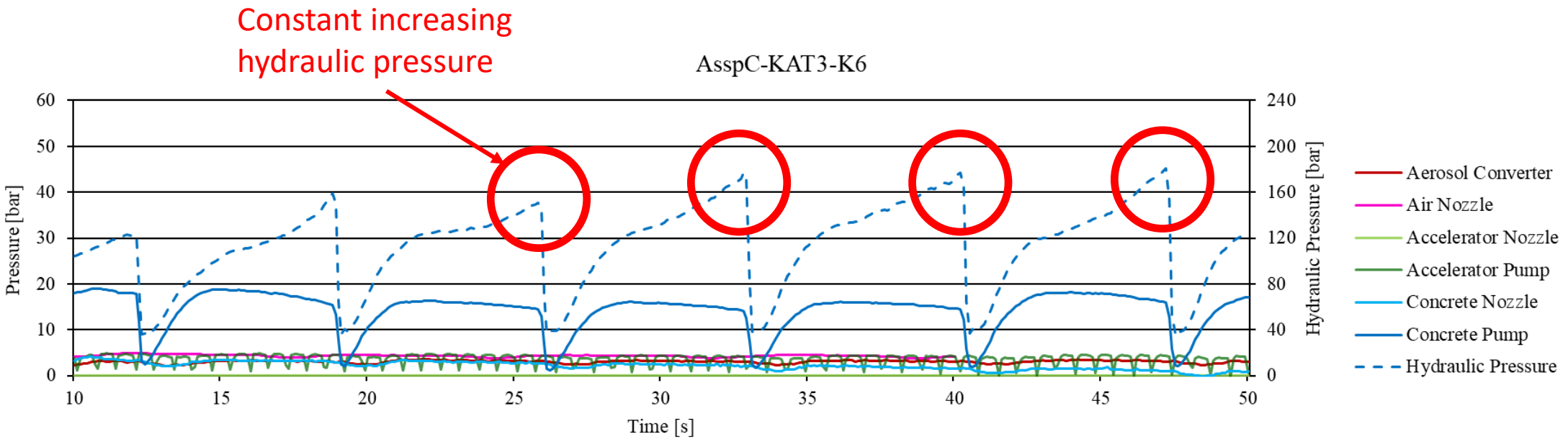
Results

Results



Comparison of the concrete and accelerator pump pressures with a suspension and a dissolution accelerator

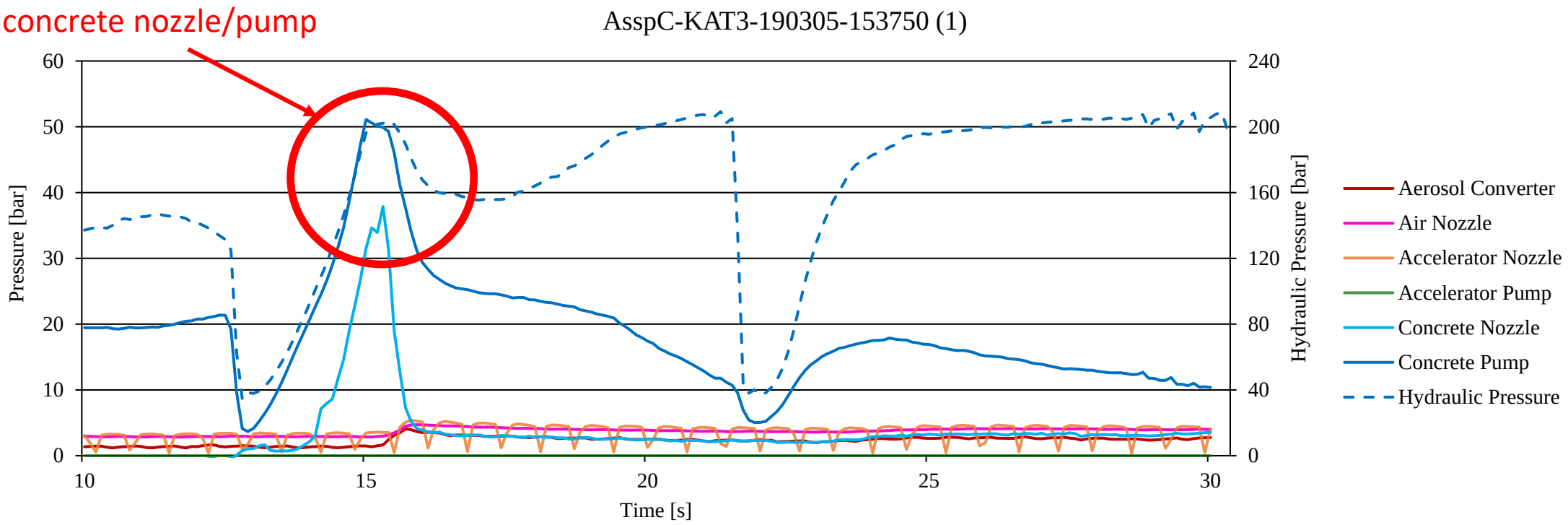
Results



Indications for an arising blockage

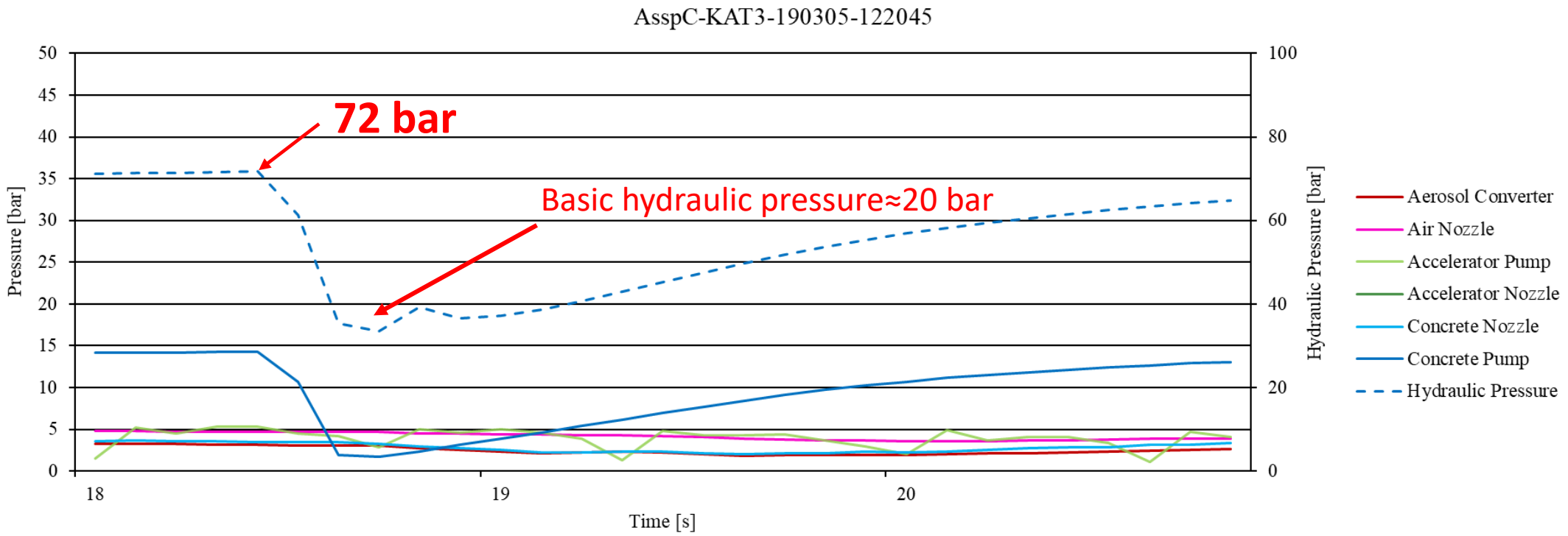
Results

Huge peak at the concrete nozzle/pump



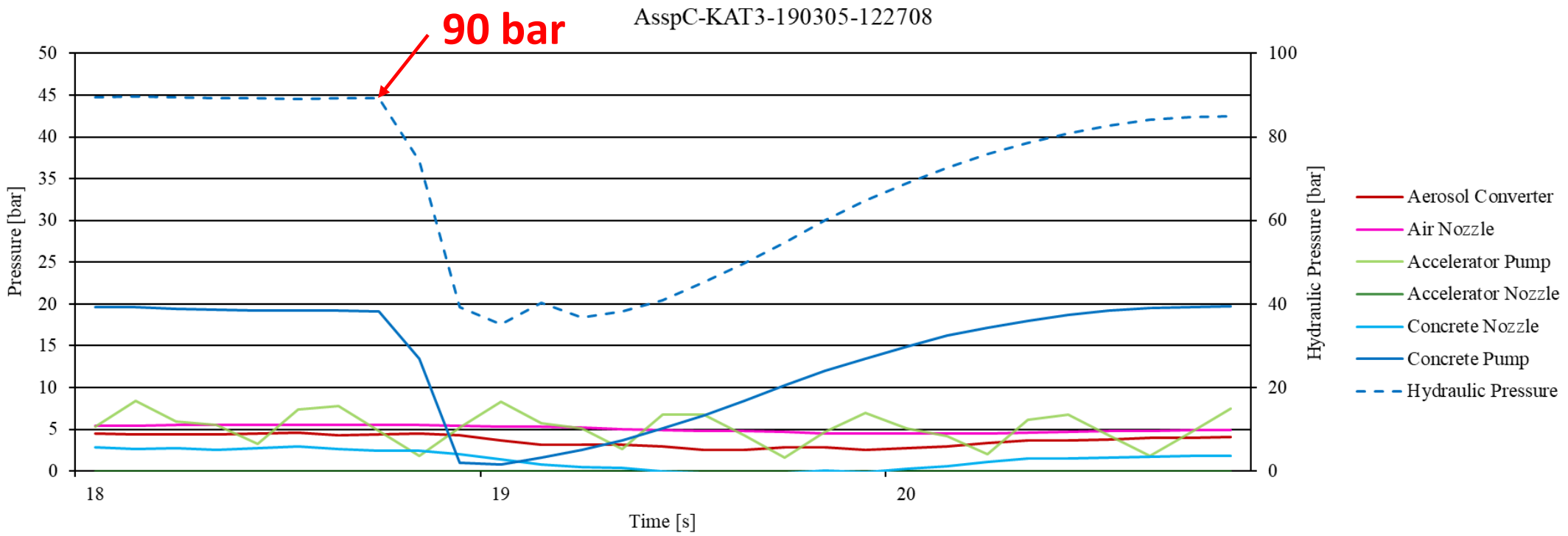
The occuring blockage

Pressure drop



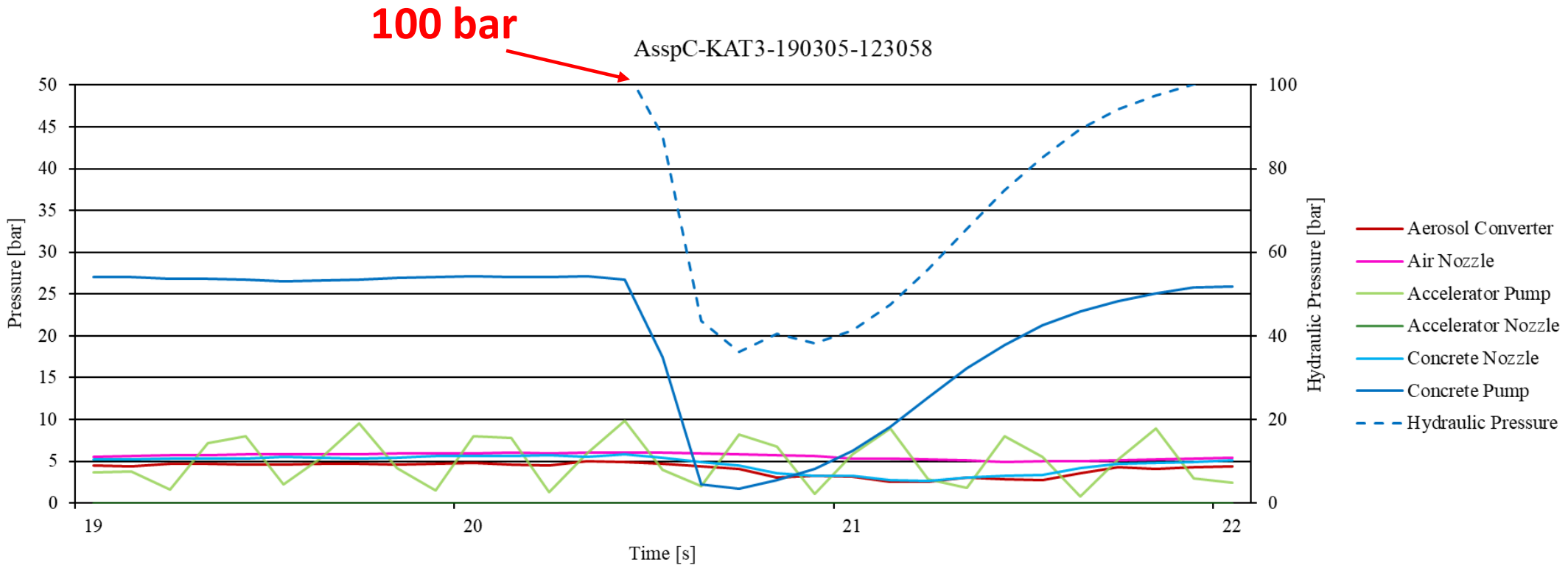
Pressure drop between two strokes at a flow rate of 12 m³/h of the reference mix

Pressure drop



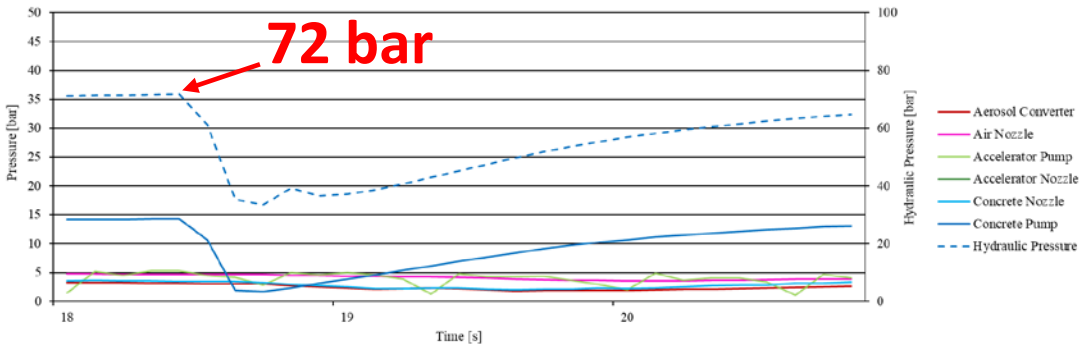
Pressure drop between two strokes at a flow rate of 18 m³/h of the reference mixture

Pressure drop

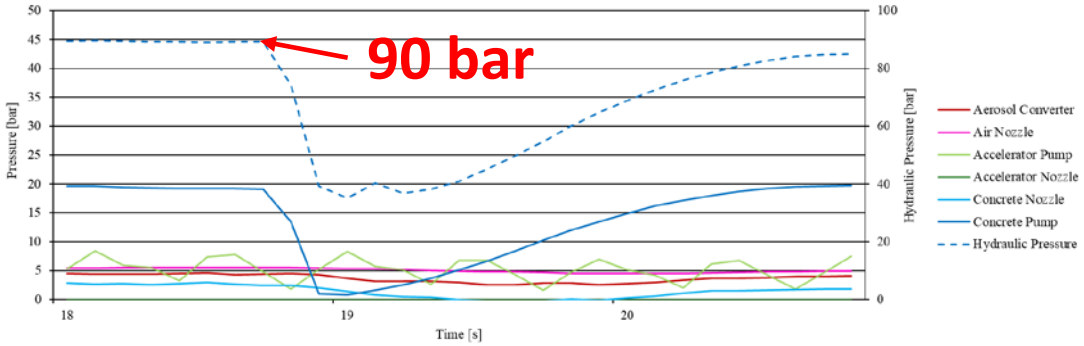


Pressure drop between two strokes at a flow rate of 24 m³/h of the reference mixture

12 m³/h

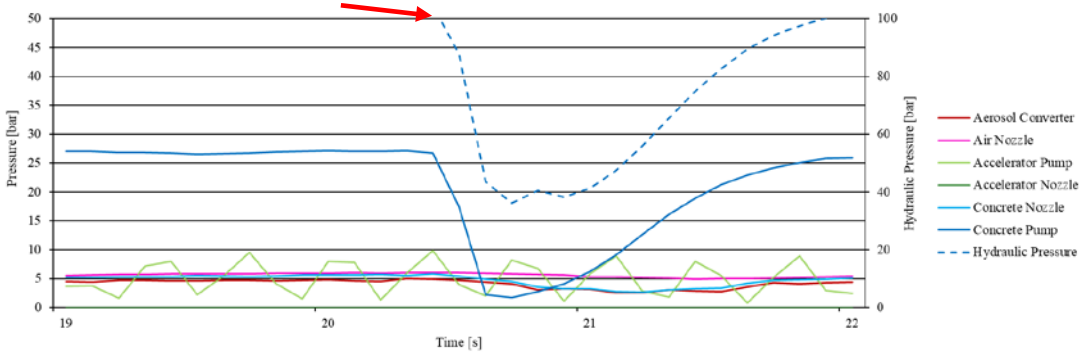


18 m³/h



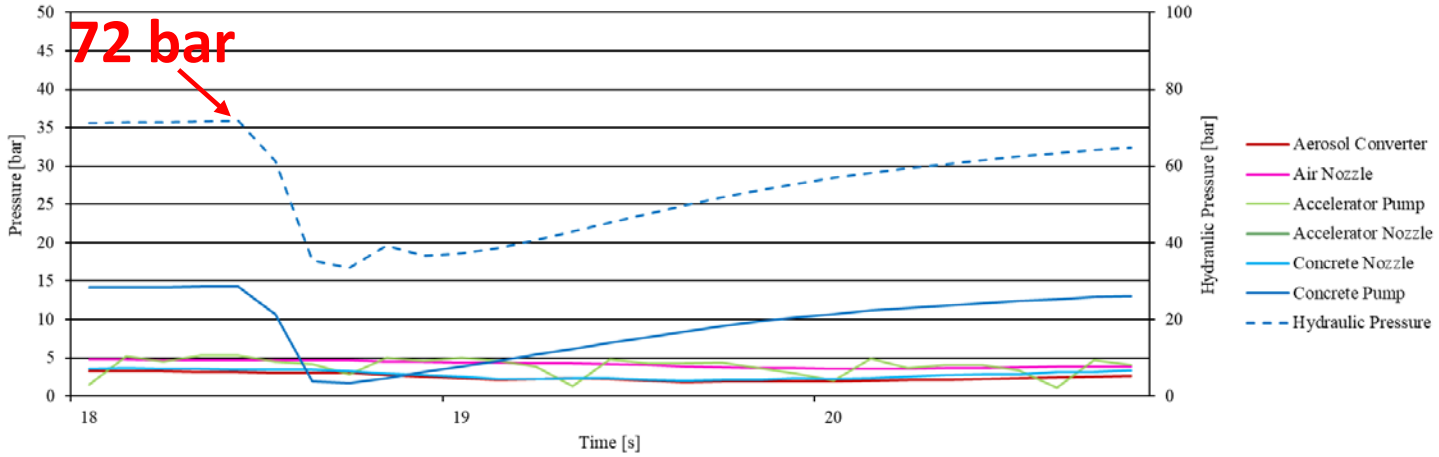
24 m³/h

100 bar

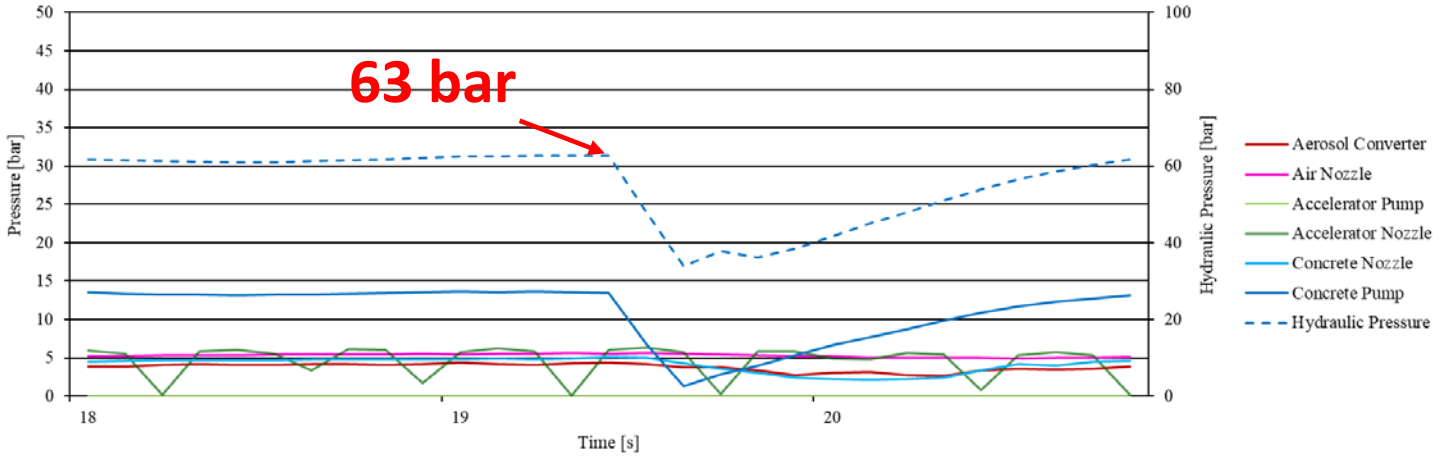


Pressure history during a pressure drop at different flow rates (reference mix)

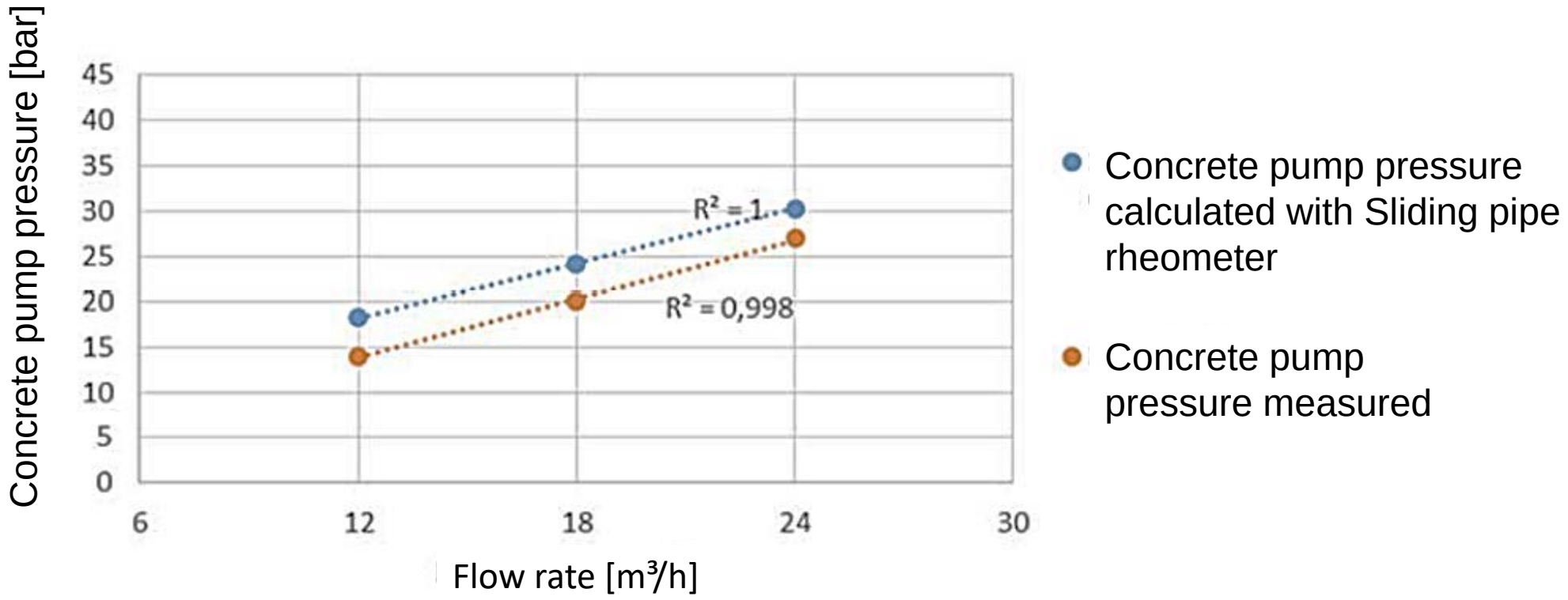
Reference 12 m³/h



w/b_High 24 m³/h



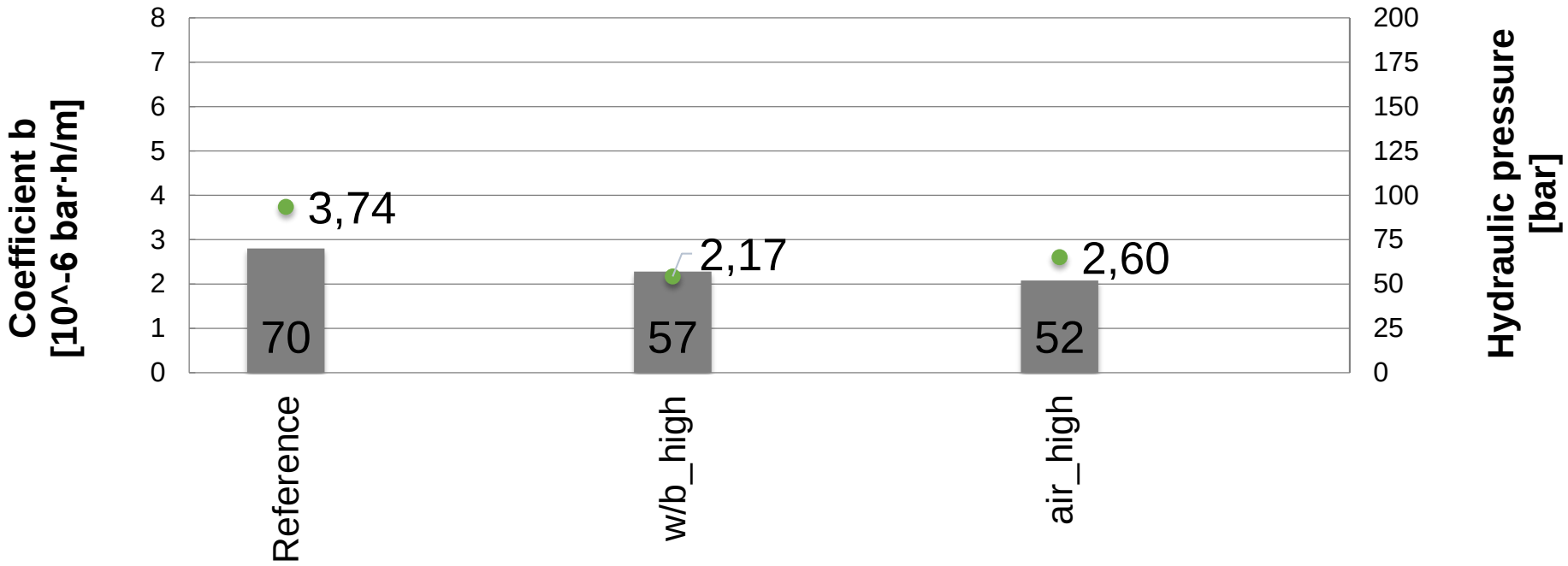
Sliper viscosity vs. Concrete pump pressure



Sliper viscosity vs. Hydraulic pressure

Mix-Design		**Reference**	**w/b_high**	**air_high**
w/b		0,49	0,52	0,49
CEM II	[dm³/m³]	131	132	133
Water	[dm³/m³]	197	**208**	196
Aggregate ≤ 0,125 mm	[dm³/m³]	46	46	42
Air void content	[dm³/m³]	32	15	**90**
Paste volume	[dm³/m³]	406	401	461

Sliper viscosity vs. Hydraulic pressure



Resume

- Pumpability/Workability of shotcrete depends on:
  - Stability of the mix-design
  - Paste volume
  - Rheology of the paste

- Higher flow rates result in higher pumping pressures
- Measurements of the pumping pressures confirm that the pumpability can be estimated by using results from:
  - Filterpress
  - Sliding Pipe Rheometer

Outlook

The section of the pressure drop might be optimized

- The interrupted concrete flow, when changing between the two pistons pushing the concrete, should be optimized
- Accelerator dosing has to be adapted during the switch between the two pistons
- Uniform material streams would result in better and more homogeneous hardened shotcrete properties (strength, modulus of elasticity, chemical resistance, etc.)

Thank you for your attention!