# THE FUNDAMENTAL APPROACH OF SHOTCRETE APPLICATION FOR AN ADEQUATE STRUCTURAL PERFORMANCE

## SHOTCRETE SESSION
## NEW 506 GUIDE AND RECENT DEVELOPMENTS

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# Introduction: *The versatility of shotcrete*



Retaining walls

*Structural shotcrete ltd.*, Vancouver, 2016

Structural columns

# Introduction: *Factors affecting encapsulation*



**Encapsulation of reinforcing bars**

**Equipment**
- Condition

**Spraying technique**
- Distance between nozzleman and surface
- Air flow velocity

**Mixture properties**
- Accelerators
- Mineral admixtures
- *Consistency*

**Structural layout**
- Number of bar layers
- Bar position
- Overhead vs. sidewall
- Lap splices

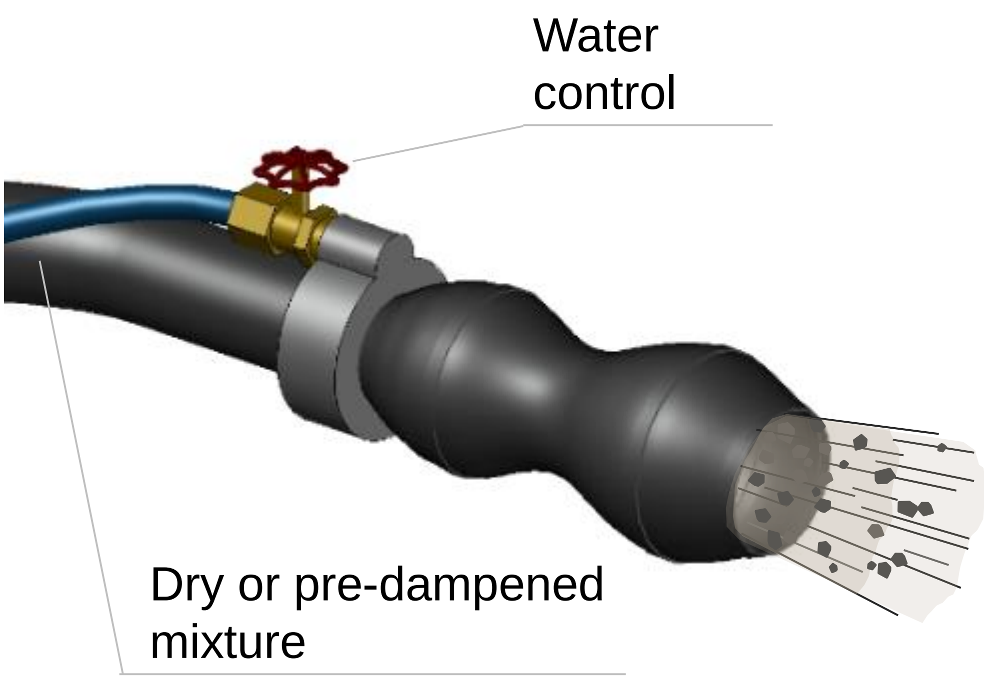
*Perfect encapsulation*

*Voids of variable geometry and position*

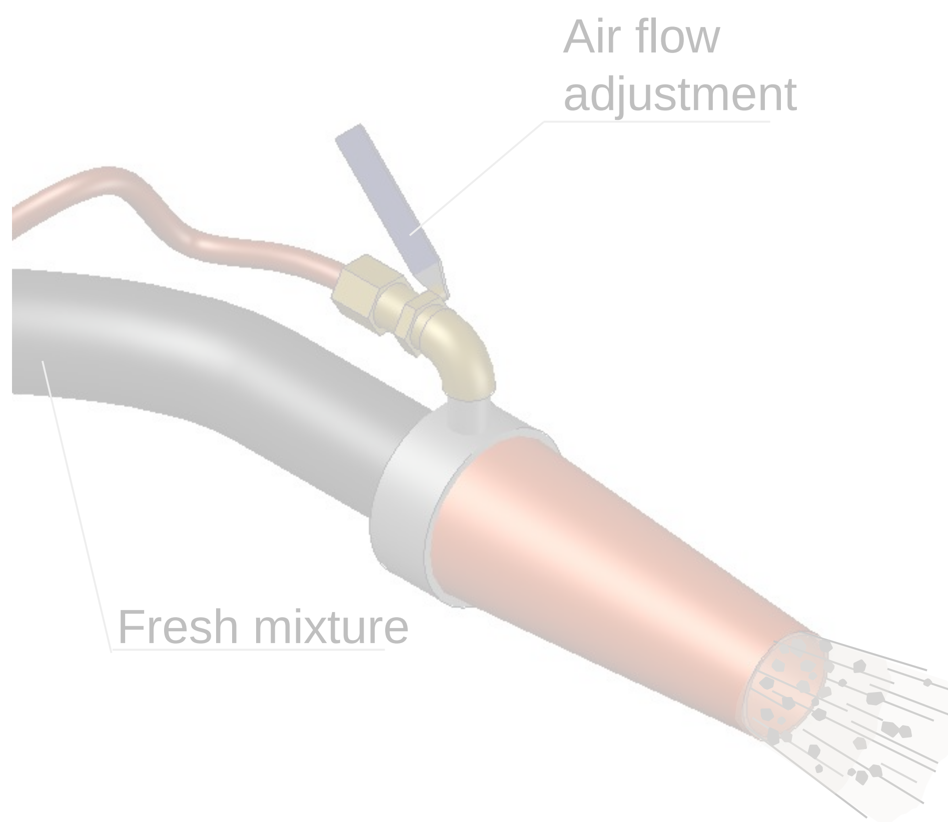
# Introduction: *Types of shotcrete process*



***DRY-MIX***

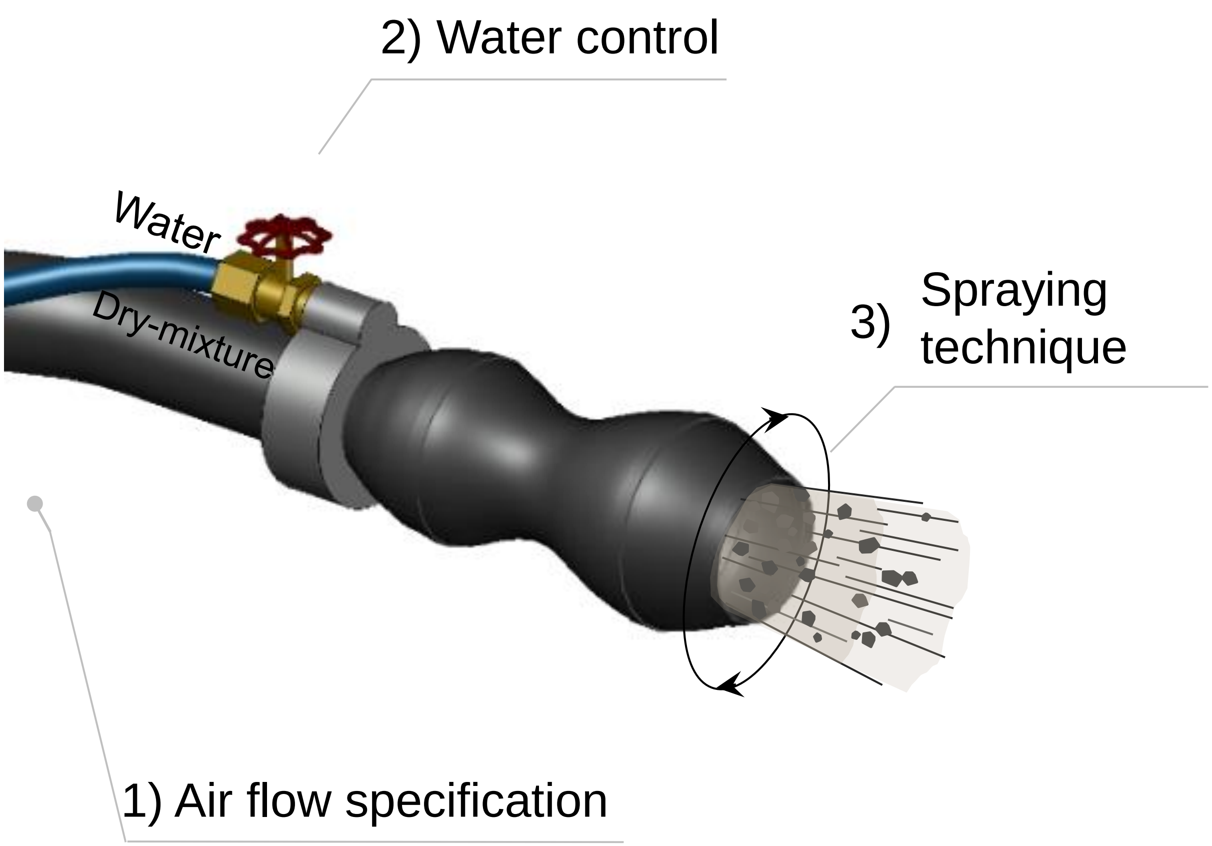



***WET-MIX***



# Introduction: *Dry-mix adjustment before spraying*

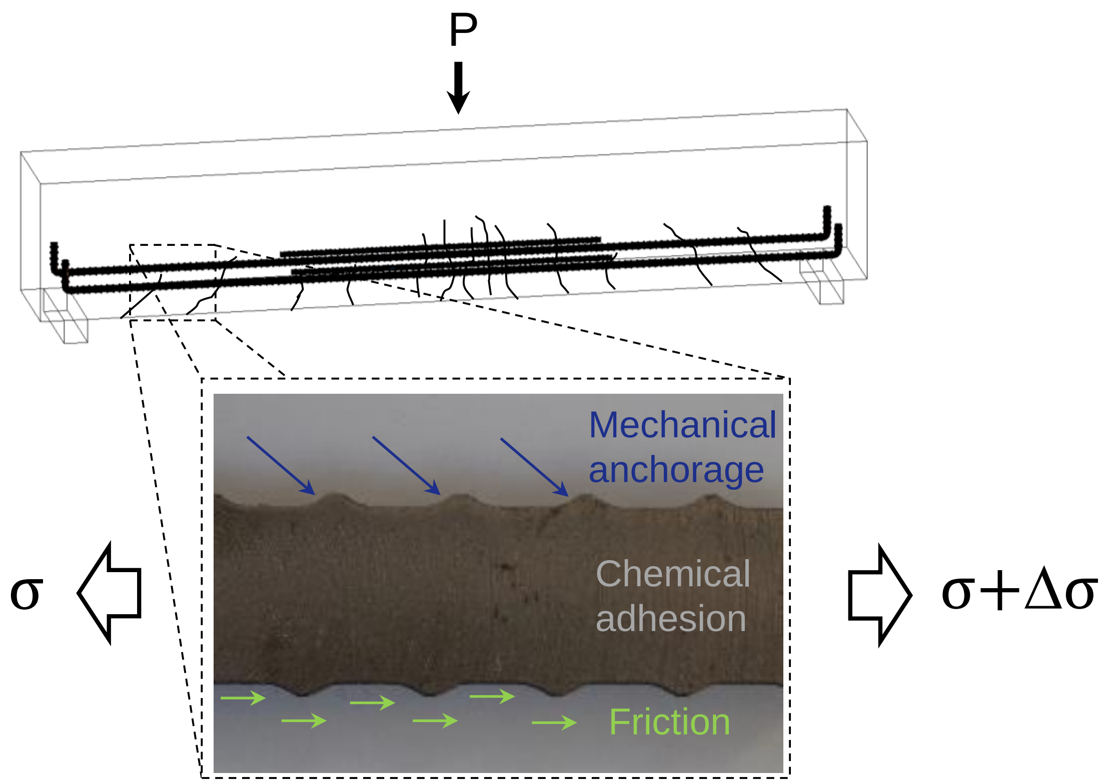


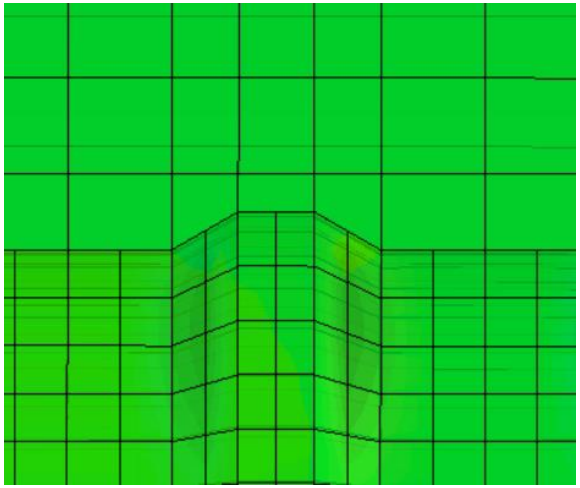




# Introduction: *The bond mechanism*





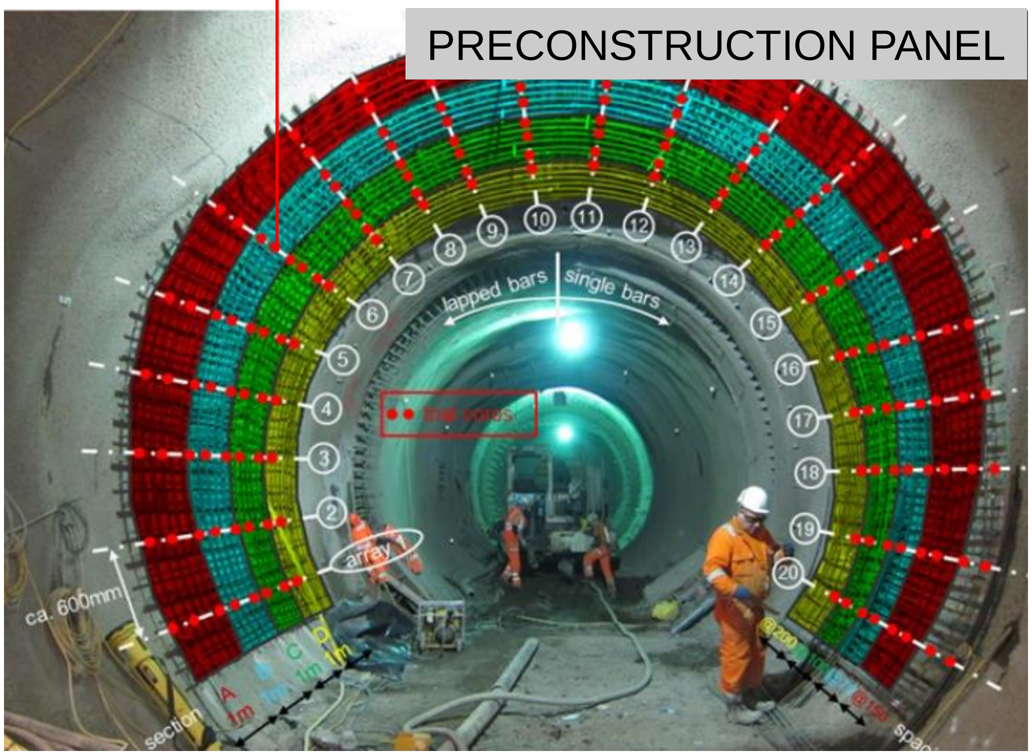

Relative slip

- $E_s/E_c \approx 6 - 8$
- Micro-cracking

Naturally, **bond will be reduced if voids** behind bars are created !

# Research problem: *Acceptance criteria*





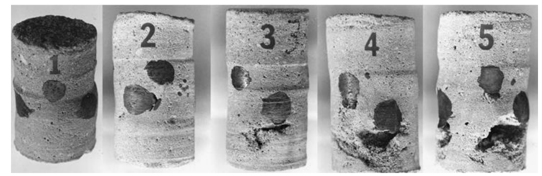

Fischer M. et al., Crossrail learning legacy, 2015

**Before**

**Acceptance criteria**

ACI 506.2-**95**

- Core grade evaluation from 1 to 5




ACI 506.2-**13**

- <u>Removal</u> of the core grade system (only intended for C660 certification)

**Now**

- Quality assessment based on experience (no correlation with bond reduction)
- Inadequate factors applied (if any) for bar splices and development lengths

# Objectives



**Study bond strength reduction caused by voids**

Design

*BOND IN CONCRETE*
*PART 2 OF 3*

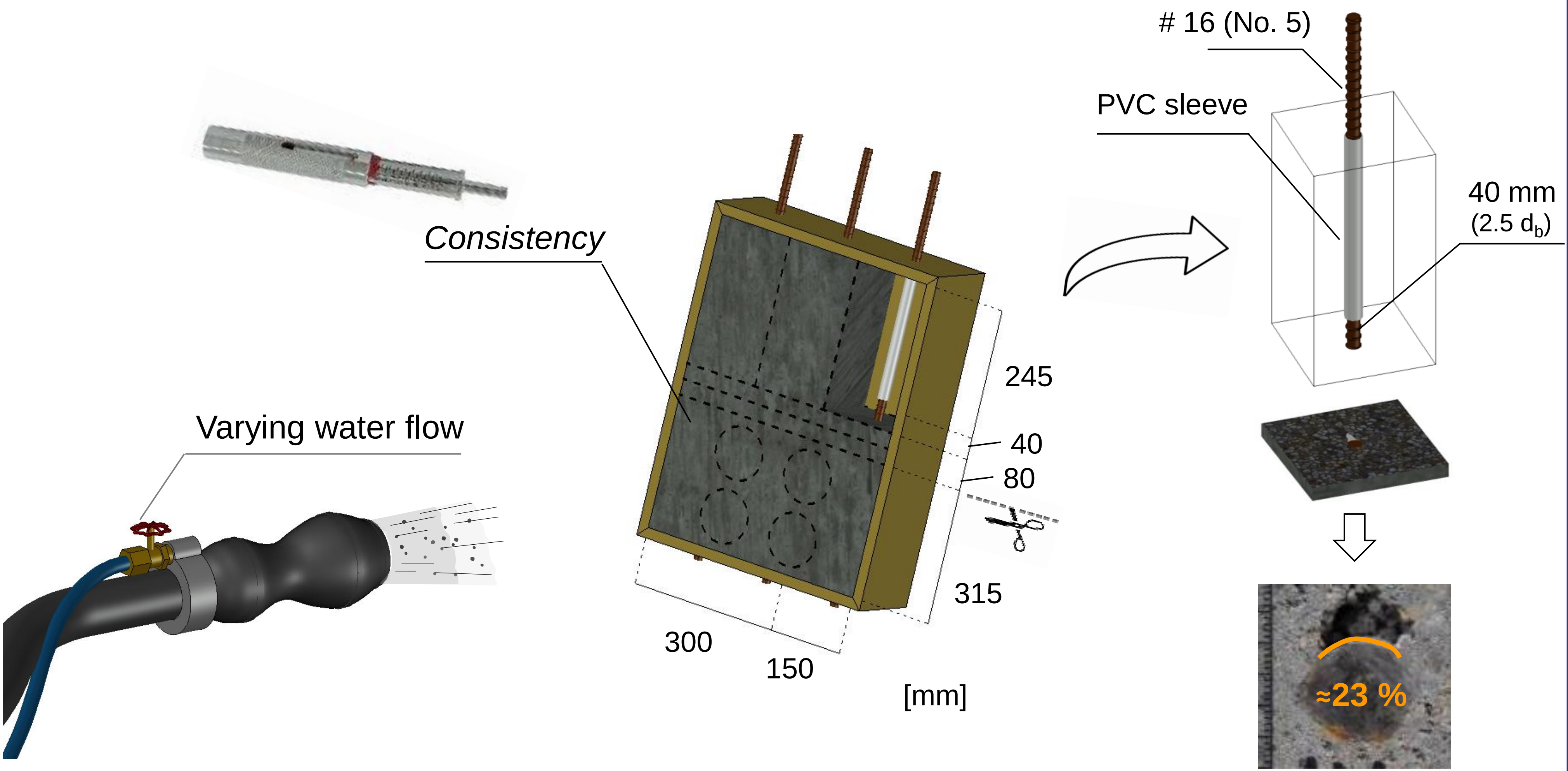
*Monday 27th March*
*1:30 p.m.*

Inspection

Concerning bond strength

# Methods: *Dry-mix pull-out specimens*

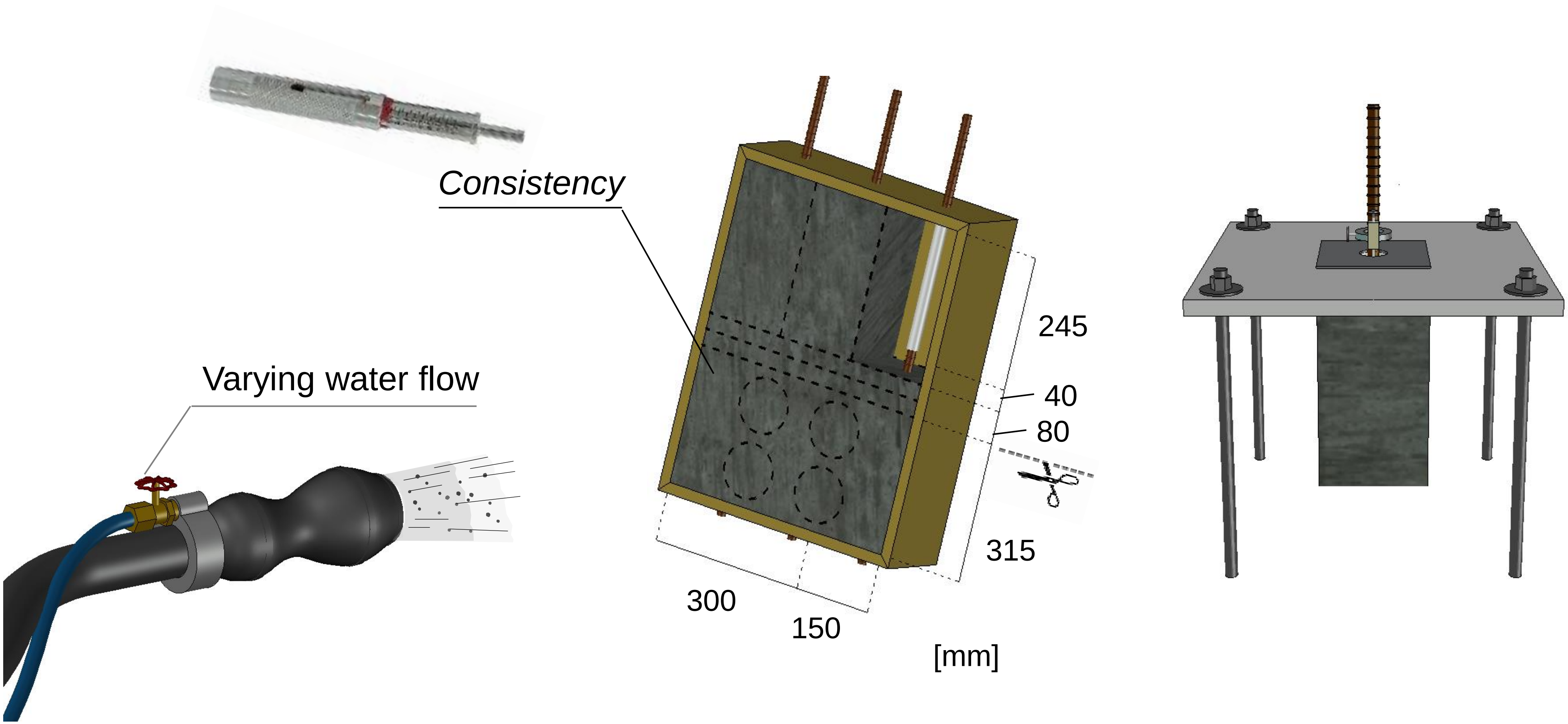





***un-bonded*** **perimeter,** ***u.p.***

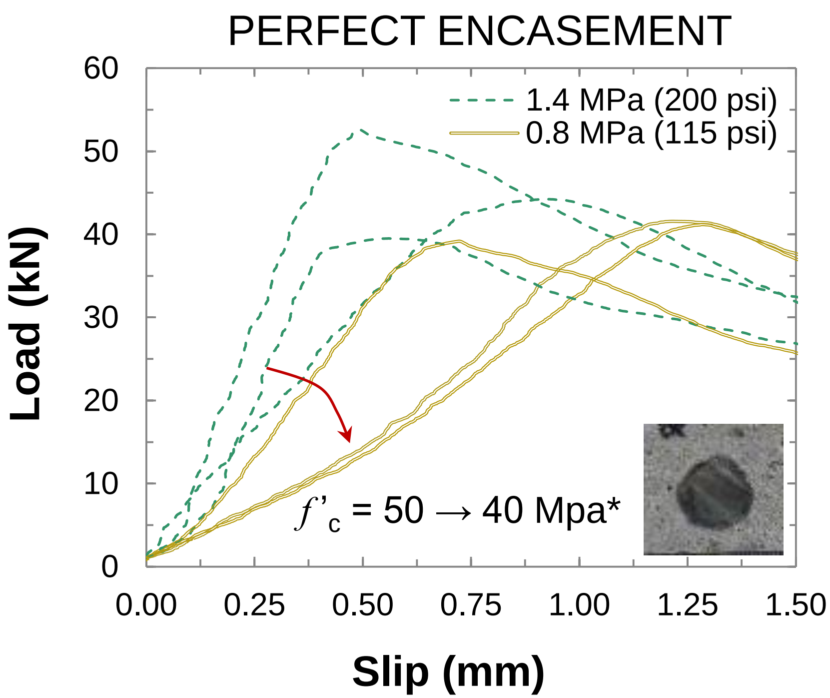
# Methods: *Dry-mix pull-out specimens*

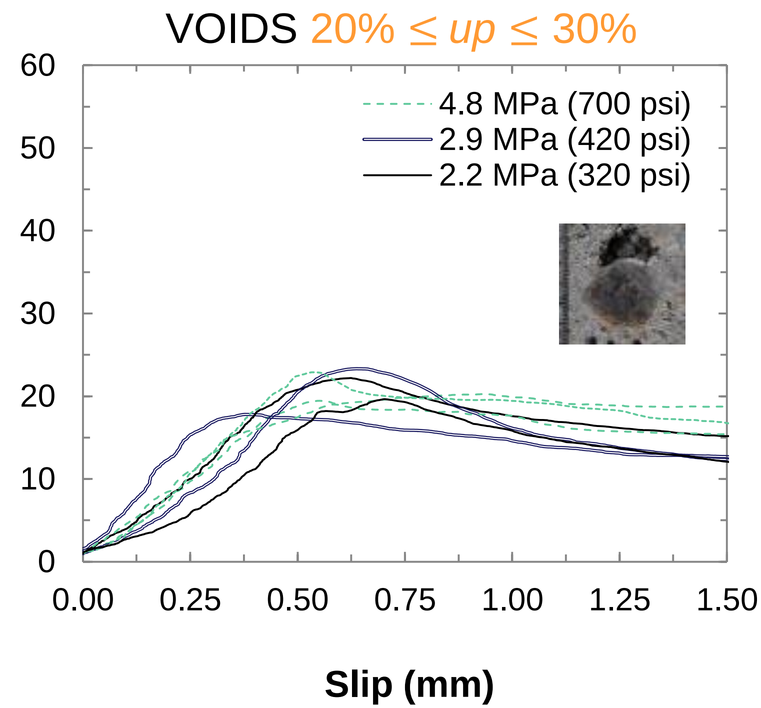




# EFFECT OF *CONSISTENCY*

# Results and discussion



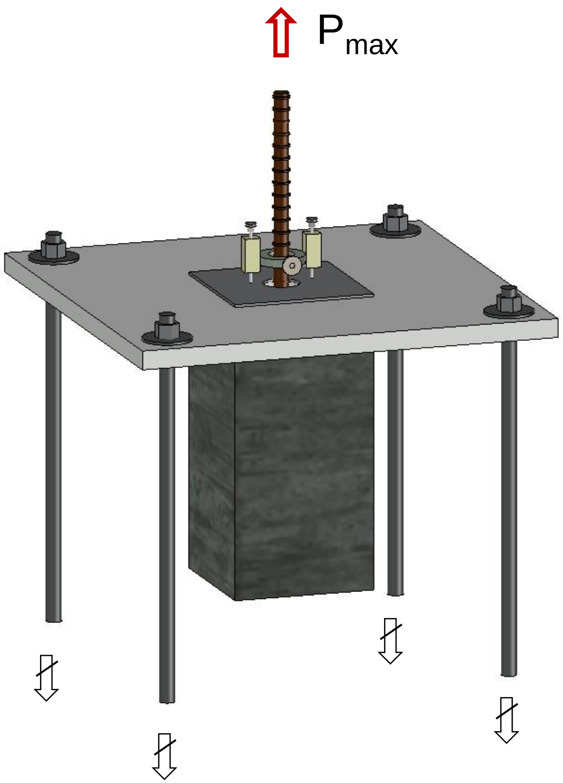

- Statistically same maximal load
- Increased slip because of weaker concrete around the bar

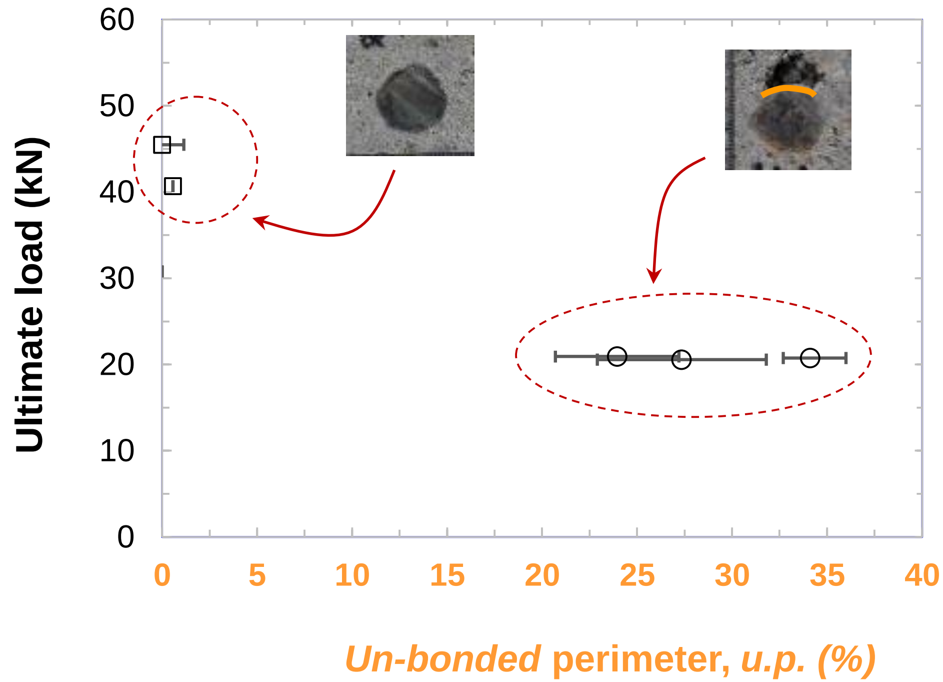
- Statistically same maximal loads
- Reduction of ≈ 50% of the maximal load

* 1 MPa ≈ 145 PSI

# EFFECT OF

# *UN-BONDED* PERIMETER




- Unable to create voids between **5 to 20 % *u.p.***
- Difficult to assess variation of ***u.p.***
- ≈ 50% of bond strength reduction

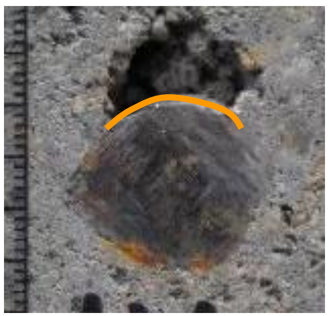
# HOW DO WE BETTER CONTROL VOID SIZES?

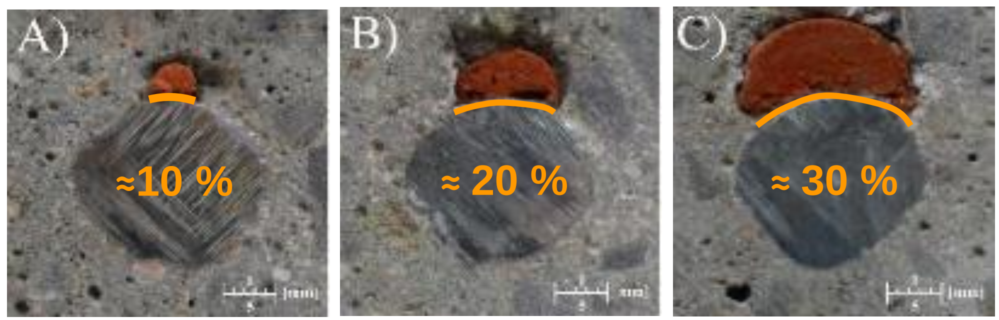
THE ANSWER LIES ON:

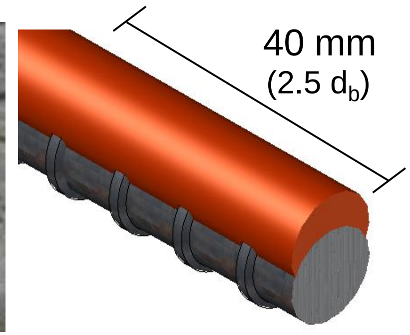
**CIP + *ARTIFICIAL VOIDS***

# Results and discussion

HOW DO WE BETTER CONTROL VOID SIZES?: **CIP +** ***ARTIFICIAL VOIDS***





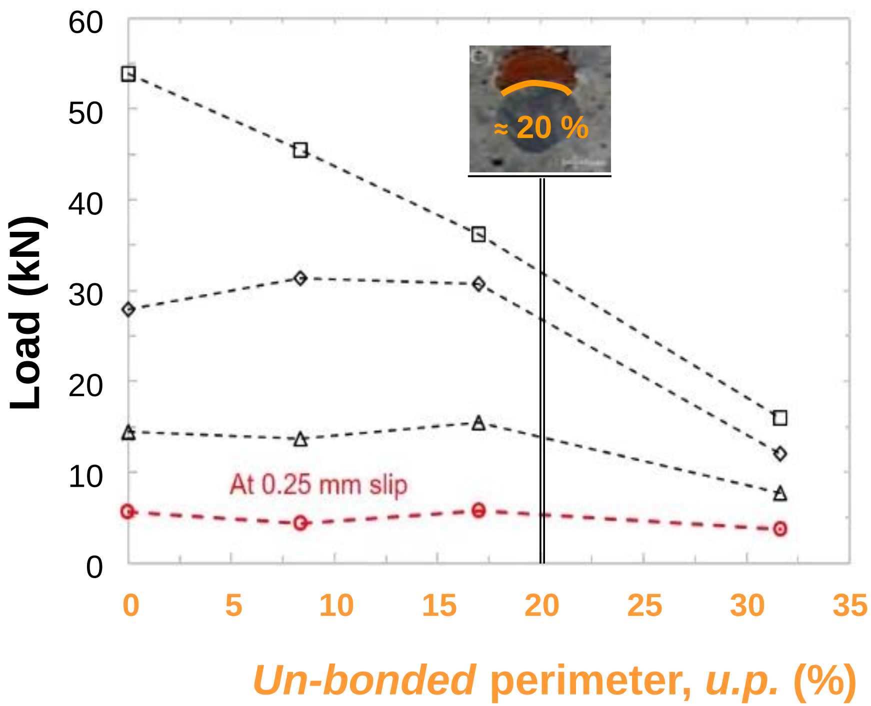

Poured shotcrete mixture with MRWR

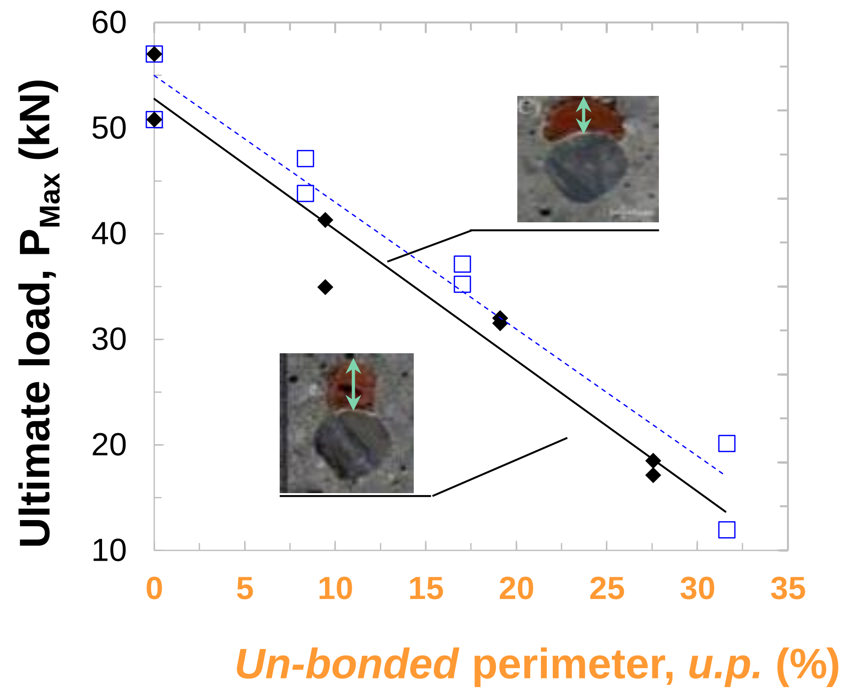
Better manoeuvrability

$w/b$ = 0.45

$D_{max}$ = 10 mm

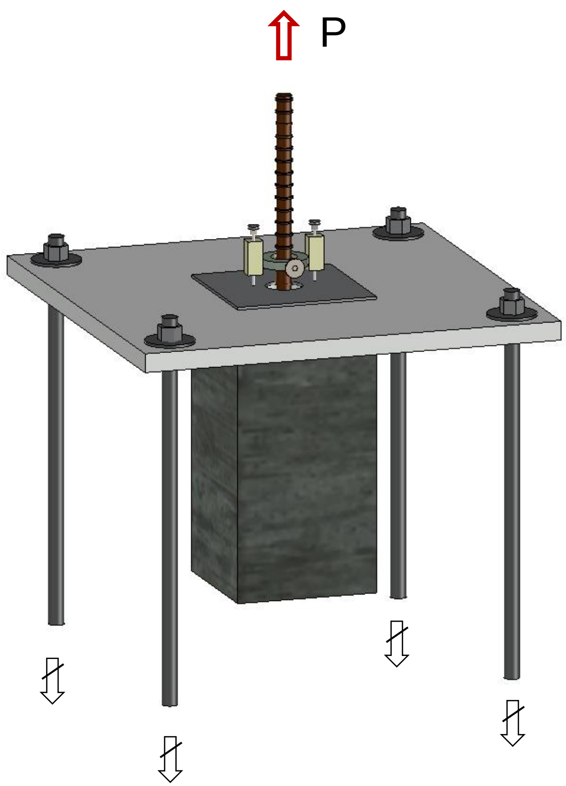
8% Silica fume



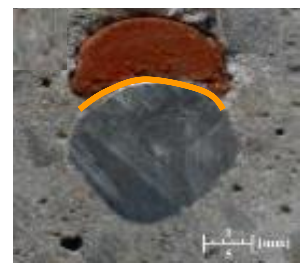




- Critical ***u.p.*** threshold of approximately 20% at service loads
- Gradual reduction at ultimate load
- Statistically same slope and intercept
- The height does not influence bond strength reduction

# Results and discussion



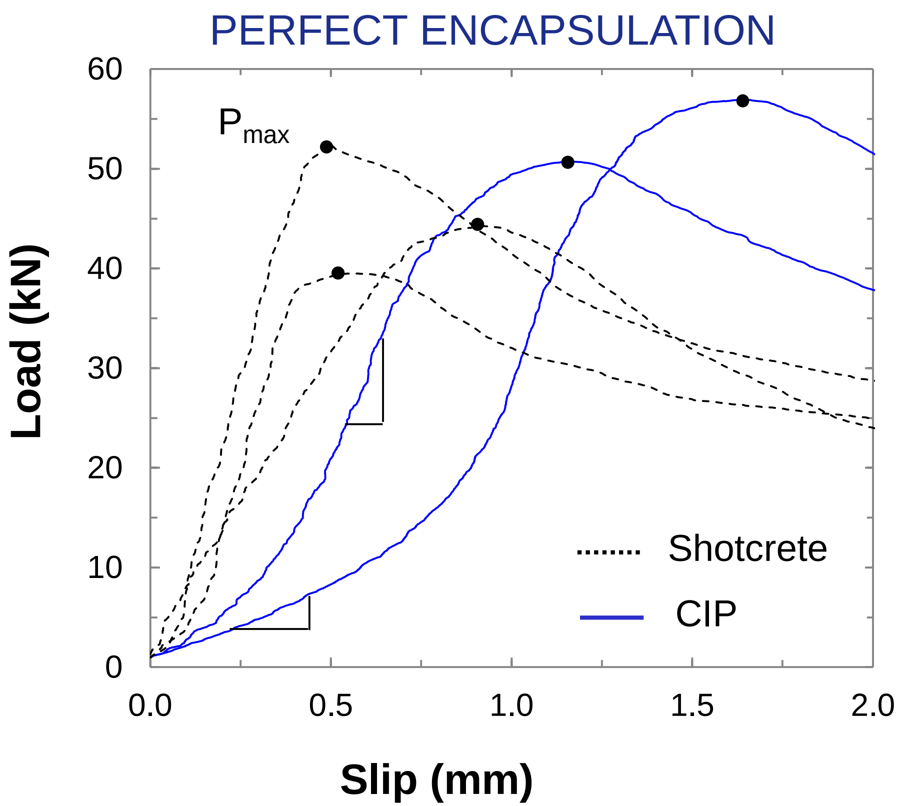

*vs.*

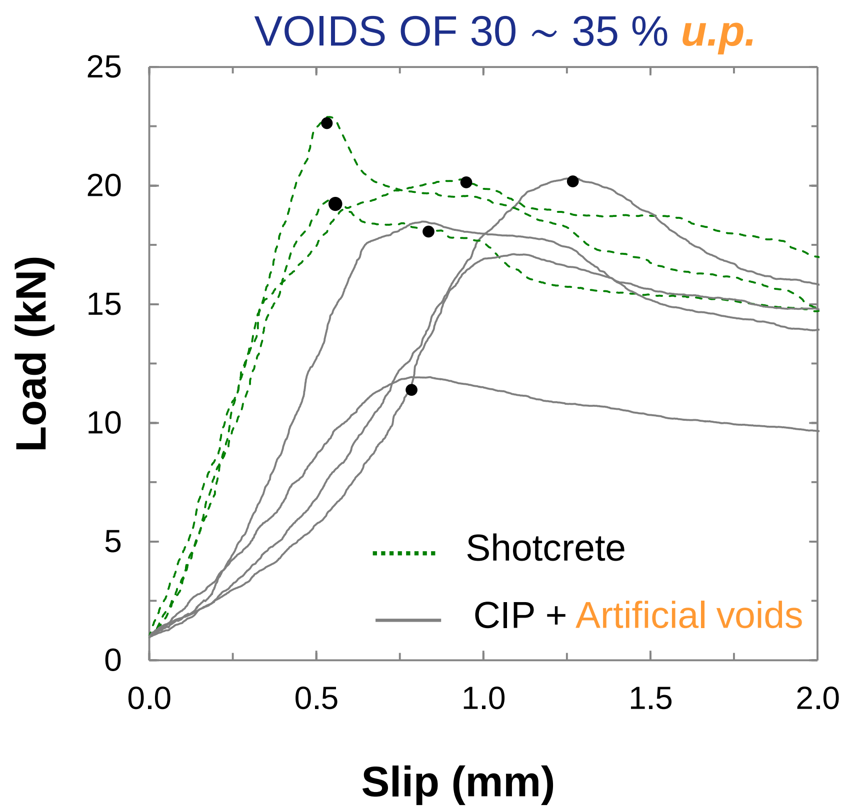


Do *artificial voids* accurately represent voids created with shotcrete ?

# Results and discussion






$H_0 : \mu_c = \mu_{BP}$

*vs.*

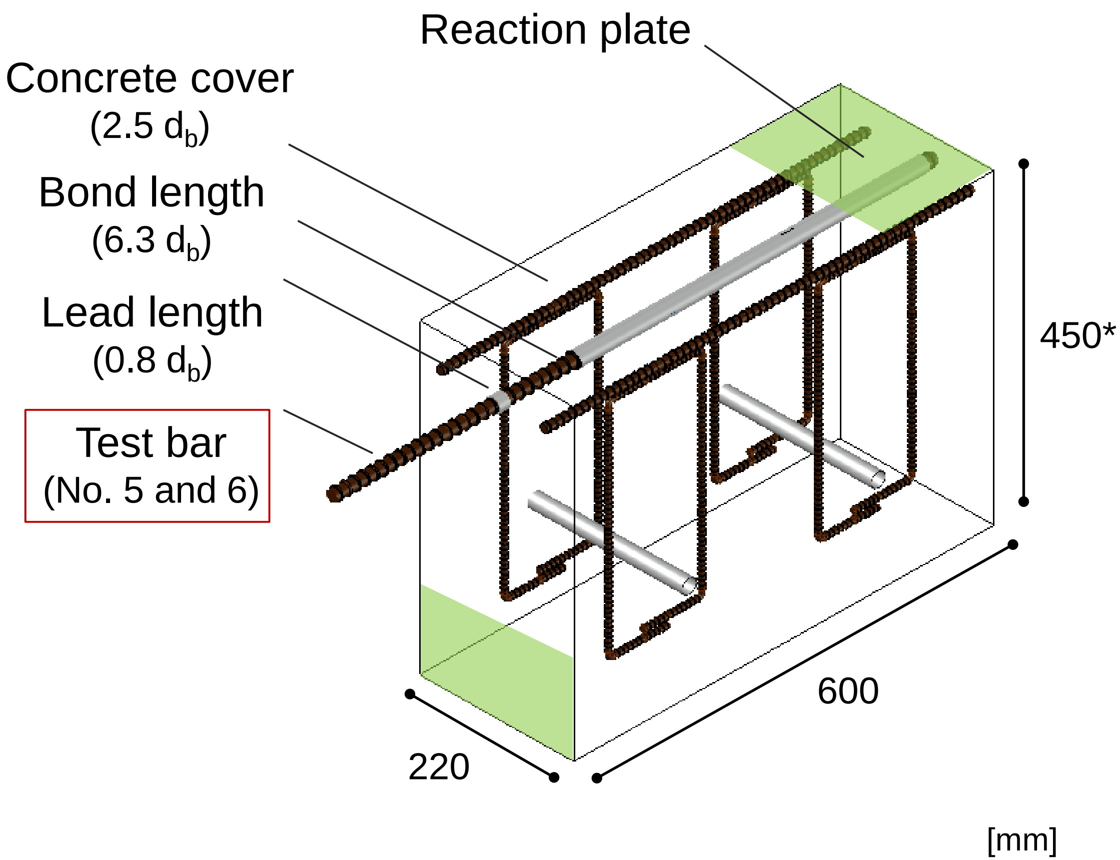
$H_a : \mu_c \neq \mu_{BP}$

$P_{max}$ are equal <u>**for both methods**</u> of concrete placement

## What is the next step?: Bonded lengths seen in structures

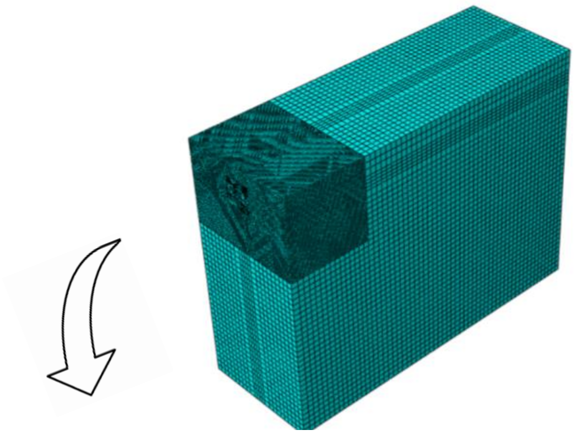
SPECIMENS: ASTM A944-10

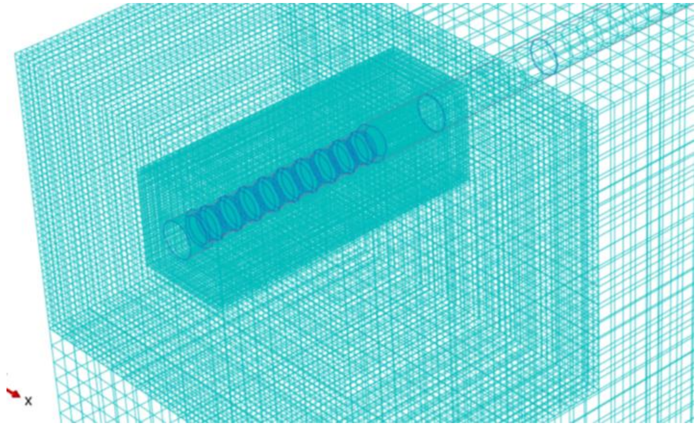
TEST SET-UP

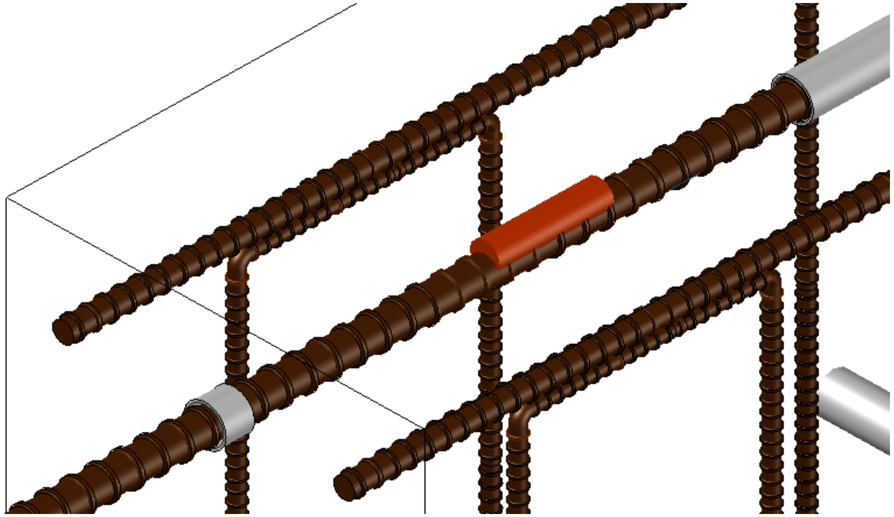



*1 inch = 25.4 mm

**What is the next step?: Bonded lengths seen in structures**







- Impact of localized voids on bond reduction
  - Stress redistribution

# Conclusion



- High compaction caused by shooting creates better bar-concrete interface in comparison with regular CIP concrete

- Low *consistencies* (≤ 1.4 Mpa) may cause « good » encapsulation but slip is enlarged

- Threshold of **≈20 % *u.p.***
  - Drastic reduction at 0.25 mm slip
  - ≈ 50% bond reduction at ultimate load

- The height of voids do no influence significantly bond strength reduction

*HELP DEVELOP NEW ACCEPTANCE CRITERIA*

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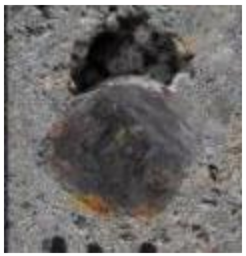
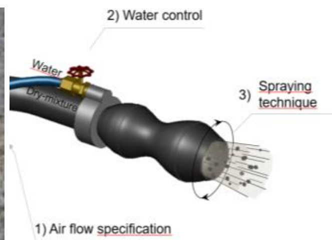
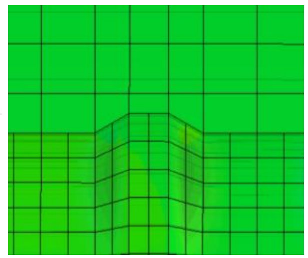
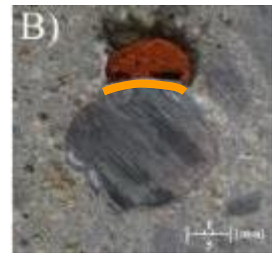
- *ON-GOING INVESTIGATION*
- *BASED ON **ONE BAR** AND PULL-OUT SPECIMENS*
- *DURABILITY ISSUES NEED TO BE ADRESSED*

# Thank you for your attention!





## Do you have any questions?