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**
- Water control
- Dry or pre-dampened mixture

**WET-MIX**
- Air flow adjustment
- Fresh mixture
Introduction: *Dry-mix adjustment before spraying*

1) Air flow specification

2) Water control

3) Spraying technique

Research problem  Objectives  Methods  Results and discussion  Conclusion
Introduction: The bond mechanism

Naturally, bond will be reduced if voids behind bars are created!
Research problem: \textit{Acceptance criteria}

Before

\begin{itemize}
  \item ACI 506.2-95
    \begin{itemize}
      \item Core grade evaluation from 1 to 5
    \end{itemize}
  \item ACI 506.2-13
    \begin{itemize}
      \item Removal of the core grade system (only intended for C660 certification)
    \end{itemize}
\end{itemize}

Now

\begin{itemize}
  \item Quality assessment based on experience (no correlation with bond reduction)
  \item Inadequate factors applied (if any) for bar splices and development lengths
\end{itemize}

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

Study bond strength reduction caused by voids

Design

Inspection

Concerning bond strength

BOND IN CONCRETE
PART 2 OF 3

Monday 27th March
1:30 p.m.
Methods: *Dry-mix pull-out specimens*

**Introduction**

**Research problem**

**Objectives**

**Results and discussion**

**Conclusion**

*Varying water flow*

*Consistency*

*un-bonded perimeter, u.p.*
Methods: *Dry-mix pull-out specimens*

**Consistency**

- Varying water flow

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

**Specimen Dimensions:**
- Width: 245 mm
- Height: 315 mm
- Depth: 300 mm
- Embedded depth: 150 mm

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EFFECT OF CONSISTENCY
Results and discussion

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

$\Rightarrow$ \hspace{1cm} Statistically same maximal loads

\[ f'_c = 50 \rightarrow 40 \text{ Mpa}^* \]

$\Rightarrow$ \hspace{1cm} Reduction of $\approx 50\%$ of the maximal load

* 1 MPa $\approx$ 145 PSI
EFFECT OF UN-BONDED PERIMETER
Results and discussion

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

Poured shotcrete mixture with MRWR

Better manoeuvrability

$w/b = 0.45$

$D_{\text{max}} = 10 \text{ mm}$

8% Silica fume

Slump flow $\approx 450 \text{ mm}$
Results and discussion

- 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
Do *artificial voids* accurately represent voids created with shotcrete?
Results and discussion

PERFECT ENCAPSULATION

VOIDS OF 30 ~ 35% \textit{u.p.}

\[ H_0 : \mu_c = \mu_{BP} \]

\[ \text{vs.} \]

\[ H_a : \mu_c \neq \mu_{BP} \]

\( P_{max} \) are equal for both methods of concrete placement.
Results and discussion

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

SPECIMENS: ASTM A944-10

TEST SET-UP

- Concrete cover (2.5 $d_b$)
- Bond length (6.3 $d_b$)
- Lead length (0.8 $d_b$)
- Test bar (No. 5 and 6)

*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 ($\leq 1.4$ Mpa) may cause «good» encapsulation but slip is enlarged.

Threshold of $\approx 20\%$ $u.p.$

- Drastic reduction at 0.25 mm slip
- $\approx 50\%$ bond reduction at ultimate load

The height of voids do no influence significantly bond strength reduction.
High compaction caused by shooting creates better bar-concrete interface in comparison with regular CIP concrete.

Low consistency (≤ 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.

Conclusion

DURABILITY ISSUES NEED TO BE ADRESSED

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?