Field Measurements of Form Pressure Exerted by Self-Consolidating Concrete

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This Presentation:
• Will not discuss the design of SCC mixes.
• Will focus upon SCC behavior in the form.
• Will discuss placement pressures.
• Will discuss formwork strength considerations.
• Will discuss formwork construction details.
• Will be focused upon vertical formwork for walls and columns.

What is Self-Consolidating Concrete?
• A very fluid concrete mix. Flows into place in the form with no additional assistance.
• A mix with paste properties such that the aggregate neither sinks or floats to the top.
• Develops an internal molecular structure that is able to resist an increase in form pressure as the height of concrete in the form increases.
• If agitated, can return to a high fluid state.

Desirable Properties of SCC from a formwork perspective:
• Rapid internal structure build-up.
• Robustness, i.e. consistent behavior load-to-load and day-to-day.
• Remains consistent from truck to point of placement.
• Not adversely affected by placement method, or is predictably consistent at the point of placement.

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presented by
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SCC Placement Pressure:

• Studies are ongoing. Some researchers feel they have enough data to predict pressure.
• Ideal mixes can result in placement pressures less than full liquid head.
• Can be dependent on the SCC producer and the readily available constituent ingredients to be used.
• Can be sensitive to variations in those ingredients (moisture, aggregate variations).

SCC Placement Pressure:

• With an unknown mix behavior, the design placement pressure should be full liquid head.
• Mix design & testing should be done well in advance of a major application of SCC (see formwork challenges).
• Can be indirectly monitored on‐site with simple instrumentation. Desirable with an unknown mix.

Formwork challenges:

• Too often, formwork decisions must be made before the SCC mix design & behavior are done.
• Without knowing SCC behavior, the decision of proper formwork design pressure is but a guess.
• Last‐minute formwork design changes due to a “slow to stiffen” SCC mix can be costly.

Formwork challenges:

• If an SCC mix is slow to develop its internal structure (or to “stiffen”), placement rates must be reduced to keep below the design placement pressure.
• This can impact the supply “train”, reducing the frequency of delivery or possibly causing concrete to remain in the truck too long.
• Placement size (volume) can help or hinder.

Formwork Considerations:

• Design placement pressure has an effect on the economics of the form system.
• Modular forms from rental stock have a “standard” rated safe placement pressure.
• Pressure ratings vary from 1,000 pound per square foot (PSF) to 1,500 PSF.
• Forms with higher safe placement pressure exist but are not always readily available.
Formwork Considerations:

- Project considerations can affect formwork.
- Required concrete finish will also influence the form system.
- Unexposed concrete usually permits the use of almost any form system.
- Architectural concrete, particularly when there are specified form tie and panel joint spacings, will almost always require custom forms.

Formwork Specifics:

- The ideal formwork for SCC would be completely water-tight.
- Modular forms can have a number of slots and tie holes that will leak paste.
- Larger unused tie holes will always leak and can adversely affect the concrete nearby.
- Euro-style modular form tie systems can be equipped with tie cones that will seal well.

Formwork Specifics (panels):

- Modular forms’ panel-to-panel joints can leak paste, depending on the style of form.
- Earlier U.S. style panels (Moduform, Steel-Ply, etc.) have a number of tie and hardware slots that will leak paste.
- Installing gaskets between these form panels is possible, but very labor intensive.

Formwork Specifics (A/C panels):

- Architectural concrete (A/C) will require joint & tie patterns almost always require job- or shop-built form panels.
- Recommended form facing consist of a flexible back-up structural layer and a high quality overlaid panel (produced for concrete forming) for the face layer.
- Joints between the face & structural layers should be offset.

A leaking seam is not the sole issue. There must be enough back pressure to prevent bleeding of the fines from the mortar.
Formwork Specifics (A/C panels):
- Interior form facing panel joints on a ganged form should be caulked with a high grade silicon caulk.
- The edges of a gang form must be carefully planned to provide an effective and easily installed seal.
- Form ties must be of a type that provide for wall thickness spacing and an effective seal. (for cones, see LinerCone - www.tsl.ca)

Formwork Specifics (all styles):
- SCC will mirror every imperfection in the form face.
- Do not permit nails to be used to locate & space reinforcing bars, as the holes will be reflected in the concrete when the panel is next used.
- Consider the attachment methods to be used for any required embeds. Ideally, they should be fastened from the back side of the form.

Tips for Preventing Bleeding at Bottoms of Forms & Panel Seams
- Put 2”x4” down boards around wall or column forms flat on surface of concrete – don’t lap at corners – 2”x4”’s should extend full length of form.
- Hold bottom of column or form studs up just enough to clear bottom down-board;
- For Architectural work, stay away from spray foam;
- Foam is no substitute for sloppy carpentry
- Assure straightness and parallel of panel edges during fabrication;
- Use of foam tape must be accompanied by adequate pressure to maintain position and seal;
- Use of down-boards, with gasket material beneath them, fastened to the floor, is a good method of blocking leakage from gaps beneath vertical formwork:

Formwork Specifics (all styles):
- Reveals, recesses and openings can be problematic when sharp, crisp corners are expected.
- These items can accumulate form release agents in the corners, which can weaken the surface of the concrete.
- Forms must be carefully separated from the concrete to avoid chips & spalls on sharp corners.
Formwork Specifics (all styles):

- SCC can easily be placed around wall block-outs, even large (wide) openings.
- Proper concrete placement around block-outs can result in the complete filling of the form underneath the block-out.
- Placement openings in the bottom form for large block-outs can be eliminated.

Formwork Specifics (form ties):

- Standard cone type rod ties for older U.S. style modular panels may leak a bit. Modular panel joints should be gasketed with foam tape.
- Euro-style modular panels and custom built gang panel can use coil ties with cones or thru rods (coil rod or Dywidag rod).
- Sealing cones with PVC pipe spacers are recommended for thru rods (see LinerCone - www.tsl.ca).

Formwork Design Considerations:

- Actual placement pressure is the greatest unknown when using SCC.
- ACI-337 and ACI-347 have been following much of the research being done in this area. Many studies have attempted to fit equations to the data obtained but no clear consensus has yet emerged.
- Recommend contacting concrete suppliers in the local area who have successfully produced SCC.

Formwork Design Considerations:

- Form failures using SCC typically occur because of overloaded ties, poorly constructed job-built fillers, bulkheads or corner conditions.
- Failures (aside from ties) are usually unstoppable leakage of the paste requiring that the placement be halted until the formwork is repaired.
- Job-built items such as bulkheads, fillers, pilasters and non-standard corner condition require careful attention to detail.

Formwork Design Recommendations:

- Establish a reasonable design placement pressure based on the SCC mix history.
- For job or shop built form panels, consider:
  - Designing the form facing for full liquid head.
  - Designing the studs and the strapping to tolerate the greatest SCC pressure.
- Consider instrumenting some ties to document actual pressures.
- Placement rate can be slowed if excessive tie leaks are observed.

Formwork Design Recommendations:

- Tie instrumentation can be as simple as a hollow plunger hydraulic cylinder and an attached gauge, installed between the form and the tie nut.
- More sophisticated sensors are available to electronically read and record load data but are quite expensive.
- The primary goal is to insure that the form ties do not exceed their safe working load.
Formwork Design Recommendations:

- Column forms are usually filled quite rapidly and very seldom will a placement rate restriction be followed.
- As such, column forms for SCC should be designed for full liquid head.
- Columns with large plan dimensions (see ACI 347 2.2.2.1.3) may be designed for less than full liquid head if an appropriate placement rate can be held.

• For column forms, consider the following:
  - A ready-mix truck will contain about 8 yards.
  - Most placement methods can empty the truck in an hour.
  - A 24" square column using 8 yards of concrete would be 54 feet tall, for a placement rate of 54 feet per hour.
  - A 72" square column using 8 yards of concrete would be 6 feet tall, for a placement rate of 6 feet per hour.

The point: column concrete placement rates rarely conform to a specified value.

• Thank you for your attention.
• Questions?