Early Age Thermal Cracking Control In Mass Concrete Shearwalls Using High Strength SCC

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CONTENT

- Introduction
- Objectives
- Structural Design Considerations
- Concrete Mixture and Temperature Rise Evaluation
- Temperature Monitoring and Thermal Control
- Conclusion
INTRODUCTION

• 3 Civic Plaza - 56-storey mixed-use development
• Massive exterior shearwalls and concrete
• Exposed architectural concrete requirement
• CSA temperature approach in mitigating early-age thermal cracking
INTRODUCTION

56-storey mixed-use development, Surrey BC (Construction 2014-2017)

Design inspiration
INTRODUCTION

• Massive exterior shearwalls
  Thickness: 1.4 m – 0.6 m (bottom – Top)
  Perforated window openings
  Corrugated architectural surface

• Concrete requirement
  Compressive strength: Min. 65 MPa
  F2 exposure: 4 – 7% entrained air
INTRODUCTION

- CSA A23.1-14 requirements for mass concrete elements of 1.0 m or more in thickness – temperature control approach:

<table>
<thead>
<tr>
<th>Clause 7.5.3 – Internal core and surface temperature differential</th>
<th>Max. 20 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clause 8.5.5 – Concrete temperature during hydration</td>
<td>Max. 70 °C</td>
</tr>
<tr>
<td>Clause 8.5.5 - Concrete placing temperature</td>
<td>Max. 25 °C</td>
</tr>
</tbody>
</table>
INTRODUCTION

- CSA A23.1-14: Formwork / Protection Removal

### Table 20

**Maximum permissible temperature differential between concrete surface and ambient to minimize cracking — Wind up to 25 km/h**

(See Clauses 7.1.2.5 and 7.5.3 and Figure D.2.)

<table>
<thead>
<tr>
<th>Thickness of concrete, m</th>
<th>0†</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>20</th>
<th>r more o</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3</td>
<td>29</td>
<td>22</td>
<td>19</td>
<td>17</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>22</td>
<td>18</td>
<td>16</td>
<td>15</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>18</td>
<td>16</td>
<td>15</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>17</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>&gt; 1.5</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

*Length shall be the longer restrained dimension and the height shall be considered the unrestrained dimension.
†Very high, narrow structural elements such as columns.
OBJECTIVES

• Core temperature < 70 °C
• Minimize concrete temperature rise
• To develop a thermal control procedure guideline for construction - mitigate thermal cracking at early ages
  
  Practical and economical

  Minimum insulation for temperature differential < 20 °C

  Minimum insulation period to increase formwork productivity
STRUCTURAL DESIGN CONSIDERATIONS

- Design Standards
- Potential factors of early-age thermal cracking
- CIRIA C660 simplified procedure assessment
STRUCTURAL DESIGN CONSIDERATIONS

- Design Standards
  - Minimum reinforcement requirement for flexural cracking - CSA A23.3 – 04.
  - Early-age thermal cracking - no current design standards available
STRUCTURAL DESIGN CONSIDERATIONS

• Potential factors of early-age thermal cracking:
  - restrained thermal contraction
  - drying shrinkage
  - autogenous shrinkage
  - excessive temperature differential
STRUCTURAL DESIGN CONSIDERATIONS

• CIRIA C660 simplified procedure assessment
  early age (3 days) cracking
  Target crack width 0.3 mm
  Suspended slab restraint – not considered

• Horizontal shear reinforcement determined from strength analysis (i.e. ductile shear wall force demand under probable seismic shear force and factored wind shear forces) exceeds the minimum amounts set forth by CIRIA C660.

Typical shearwall reinforcement detail with idealized structural model
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

• Concrete Mixture
• Temperature Rise Evaluation - Field Mockup
• Mix Design Revision
• Initial Thermal Control Plan for Construction
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

• Concrete Mixture

  SCC mix (Ready mix, proprietary)
  nominal compressive strength: 65 MPa at 56 days
  MSA: 14 mm (25% crushed and 75% angular natural, Granite Moraine)
  air content: 4 – 6%
  slump flow: 650 mm +/- 70 mm

<table>
<thead>
<tr>
<th>Items</th>
<th>Mix design information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Portland limestone cement (5-15% limestone), 53% of total cementitious</td>
</tr>
<tr>
<td>Type F Fly ash</td>
<td>44% of total cementitious</td>
</tr>
<tr>
<td>Silica fume</td>
<td>3% of total cementitious</td>
</tr>
<tr>
<td>WCM ratio</td>
<td>0.28</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>47% of total aggregate</td>
</tr>
</tbody>
</table>
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

- Temperature Rise Evaluation - Field Mockup

<table>
<thead>
<tr>
<th>Locations</th>
<th>Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>interior surface</td>
<td>20 mm plywood form</td>
</tr>
<tr>
<td>exterior surface</td>
<td>plastic architectural surface former, 100 mm air space, 20 mm plywood form</td>
</tr>
<tr>
<td>sides</td>
<td>Two layers of 25 mm expanded polystyrene board, 20 mm plywood form</td>
</tr>
<tr>
<td>top</td>
<td>Two layers of 25 mm expanded polystyrene board</td>
</tr>
<tr>
<td>bottom</td>
<td>Two layers of 25 mm expanded polystyrene board</td>
</tr>
</tbody>
</table>
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

• Temperature Rise Evaluation
  - Field Mockup
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

• Mix Design Revision

<table>
<thead>
<tr>
<th>Items</th>
<th>Original mix</th>
<th>Revised mix</th>
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</thead>
<tbody>
<tr>
<td>PLC Cement</td>
<td>53% of total cementitious</td>
<td>44% of total cementitious</td>
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<td>4% of total cementitious</td>
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<td>W/CM ratio</td>
<td>0.28</td>
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<td>44% of total aggregate</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>65 MPa @56d</td>
<td>65MPa @ 91d</td>
</tr>
</tbody>
</table>
CONCRETE MIXTURE & TEMPERATURE RISE EVALUATION

• Initial Thermal Control Plan for Construction
  a). mix design revised: maximum temperature rise expected ~ 2 °C < the original mix.
  b). placing temperatures below 20 °C.
  c). in summer time, use chilled batching water. avoid pours on hot days.
  d). monitor temperatures @ internal core and surface concrete (interior and exterior surfaces)
  e). assess concrete temperature differentials (between ambient & surface concrete) for formwork removal.
TEMPERATURE MONITORING AND THERMAL CONTROL

• 1st Massive Architectural Shearwalls
• Temperature Monitoring & Thermal Control
• Thermal Management Plan modification
• 1st Massive Architectural Shearwall at the Ground Floor
  - 23 m long
  - pour height 4.5 m
  - on the concrete foundations
  - poured at end of May 2015
TEMPERATURE MONITORING AND THERMAL CONTROL

Formed wall prior to pour

Temperature sensor locations
TEMPERATURE MONITORING AND THERMAL CONTROL

- Temperature Monitoring & Thermal Control
- Temperature rise
- Temperature differential
- Formwork removal ($\Delta T < 15 \, ^\circ C$)
TEMPERATURE MONITORING AND THERMAL CONTROL

- Temperature Monitoring & Thermal Control

*Exterior Surface after formwork removal*
TEMPERATURE MONITORING AND THERMAL CONTROL

• Thermal Control Plan modification

- 80 similar 12.5 m long shearwall productions
- Temperature monitoring for each pour – impractical and not economical
- Contractor requested cost-effective TCP:
  - Max. 2 days – interior plywood formwork in place
  - Max. 7 days – exterior architectural formwork in place

- Construction top priorities:
  - Reducing formwork turnaround time
  - Minimizing early-age thermal cracking at exterior architectural surfaces
TEMPERATURE MONITORING AND THERMAL CONTROL

- Modified TCP guideline throughout the project to provide adequate but not excessive temperature control:
  a). placing temperature < 23 oC.
  b). after initial 24 hours curing, “crack” all plywood forms to increase the cooling rate.
  c). after initial 48 hours curing, remove the formwork at interior side.
  d). keep the formwork at the exterior architectural surface side in place as long as possible.
CONCLUSION

• A mockup specimen with actual wall thickness and formwork was successfully used for developing construction temperature control procedures in mitigating early-age thermal cracking of the high strength massive concrete shearwalls.

• The mockup specimen provided accurate information of the maximum temperature rise in the structure. Effectiveness of insulation provided by the formwork in the construction environment could also be obtained directly from the mockup temperature results.

• When concrete mix design proportions or adiabatic temperature rise information is not available, numerical simulation of the temperature rise and thermal gradients across concrete mass is often impractical. For relatively “small” size elements with mass concrete, this approach may be effective in developing construction thermal control plan to minimize early-age thermal cracking.