Conditions for Frost Damage

• Sufficient Internal Moisture
  – Generally > 75-80% saturation

• Freezing Conditions
  – Cold enough to freeze water in pores (colder than 28-30°F)
  – Repeated freezing and thawing increases damage
Types of Frost Damage

- **Surface Scaling**
  - Associated with de-icing salt use
  - Most common frost damage type

- **Internal Damage**
  - Usually requires many freeze-thaw cycles

- **D-cracking**
  - Non-durable aggregates
Preventing Surface Scaling

• Maximum w/cm of 0.45
  – Reduced freezable water and reduced permeability

• 4,500 psi before repeated freeze-thaw
  – Adequate curing to reduce freezable water
  – Adequate curing to reduce carbonation
  – Adequate strength to resist frost expansion

• Entrained air
  – 18% by volume of paste (Table 4.2.3.2.4)
Surface Scaling
Preventing Surface Scaling
so what has changed?

- Now 4,500 psi (was 3,500)
- Clarification of:
  
  4,500 psi before repeated freeze-thaw

  versus

  \[ f'_c = 4,500 \text{ psi (ACI 318)} \]

  (average strength at time of freeze-thaw
  versus design strength)
Curing for 4,500 psi

Age, days

Strength, psi

0.45 w/c All Cement

0.45 w/cm 50:50 Slag:Cement
Curing for 4,500 psi

- **0.45 w/c All Cement**
- **0.45 w/cm 50:50 Slag:Cement**

Graph showing strength in psi over age in days. The graph compares the curing behavior of different cement mixtures.
Curing for 4,500 psi

- 0.45 w/c All Cement
- 0.45 w/cm 50:50 Slag:Cement
Curing for 4,500 psi

- 0.45 w/c All Cement
- 0.45 w/cm 50:50 Slag:Cement
Curing for 4,500 psi

• “Old” Experience of 7-day Curing
  – Adequate for all-cement
  – Not adequate for high cement replacement

• Curing Requirement Should Reflect Actual Mixture Requirements
Preventing Surface Scaling
so what else has changed?

• Added Exposure Class F3b
  – No restriction on supplementary cementitious materials for machine-finished surfaces
  – Based on field observations of mixtures with high flyash contents
  – ACI 318 Exposure Class F3 still limits supplementary materials
Clarification of Air Content Table (Table 4.2.3.2.4)

<table>
<thead>
<tr>
<th>Maximum aggregate size, in.</th>
<th>Air content, percent</th>
<th>Exposure F1</th>
<th>Exposure F2 and F3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8</td>
<td></td>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>1/2</td>
<td></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>3/4</td>
<td></td>
<td>6.5</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>6.5</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Clarification of Air Content Table (Table 4.2.3.2.4)

• Air content is 18% of paste
  – Concrete with rounded aggregate often has lower paste content
  – Air contents calculate to about 1 percentage lower

• Rounded to nearest 0.5%
• Tolerance ±1-1/2 percent
Internal Damage
Preventing Internal Damage

• Maximum w/cm of 0.45 (0.50 for mild)
  – Reduced freezable water and reduced permeability

• 3,500 psi before repeated freeze-thaw
  – Adequate curing to reduce freezable water
  – Adequate strength to resist frost expansion

• Entrained air
  – 18% by volume of paste (Table 4.2.3.2.4)
    Slightly less for mild exposure
D-cracking
Preventing D-cracking

- Use durable coarse aggregate
  - D-cracking can happen on corners of vertical surfaces if moisture exposure is adequate
  - State DOT’s are best source of information on durability of coarse aggregate
Future Changes

• Examination of Field Exposure Sites
  – Most freeze-thaw data is based on accelerated lab tests
  – Field data will be used to possibly modify future recommendations (as was done for supplementary cementitious materials limitation)

• Other Changes to be Determined
Comments?

Questions?