Chapter 3
Planning for Control and Prevention of Cracking Due to Heat of Hydration of Cement

Tsutomu Kanazu
CERES Inc.

24 April, 2017
3.1 General

3.2 Limit Values for Control Target
  3.2.1 Limit Values for Preventing Thermal
  3.2.2 Limit Values for Controlling Thermal Crack Widths
  3.2.3 Limit Values for Preventing DEF Cracking

3.3 Methods of Controlling Thermal Cracks
  3.3.1 General
  3.3.2 Methods for Controlling Volumetric Change in Concrete
  3.3.3 Methods to Reduce External Restraints
  3.3.4 Methods to Control Thermal Crack Widths

3.4 Methods for Preventing DEF Cracking
  3.4.1 General
  3.4.2 Control of Maximum Temperature of Concrete
  3.4.3 Measures for Concrete Members to Avoid Contact with Water

Added to Chapter 3 in the 2008 Guidelines
3.1 General

It is specified control plan shall be formulated.

To achieve the control targets of thermal cracking

Establish a proper control plan for thermal cracking in concrete

Conditions; Environment, structure type and construction

Determine specifications; design, materials, mixture proportions, execution (placing time, placing temperature, sequencing of concrete placements, curing method, etc.) and quality control
3.1 General

To achieve the targets of DEF Cracking

Establish a proper prevention plan for DEF cracking in concrete

Conditions: maximum temperature of concrete, verification position, contact conditions with water

Determine specifications:
- type of cement, mixture proportions and execution (placing time, placing temperature, sequencing of concrete placing, curing methods)
3.2 Limit Values for Control Target

How to achieve the control target

Control target \rightarrow Verification index

- Prevention of thermal cracking
- Control of thermal crack width
- Prevention of DEF cracking

\[ \text{Predicted value} \leq \text{Limit value} \]

- Chapter 4
- Section 3.2

I’ll explain.
3.2 Limit Values for Control Target

Limit value for preventing thermal cracking

Verification index  Limit value

Thermal cracking probability  5%

Thermal cracking index  1.85

Thermal cracking index is usually applied instead of thermal cracking probability because thermal cracking probability can not be predicted directly.
3.2 Limit Values for Control Target

Weibull distribution

![Graph showing thermal cracking probability vs. thermal cracking index with a limit value of 1.85]
3.2 Limit Values for Control Target

Limit value for preventing thermal cracking

Thermal cracking probability

The numerical value of 5% is considered to be a probability that thermal cracking hardly occurs. A value more than 5% may be chosen if higher probability for thermal cracking is allowed.

Equivalent limit value of thermal cracking index is 1.85

\[
\text{Thermal cracking index} = \frac{\text{Splitting tensile strength}}{\text{Predicted tensile stress}}
\]
3.2 Limit Values for Control Target

Limit value for controlling thermal crack width

Verification index

- Thermal crack width

Limit value

- Values based on Specifications by JSCE Recommendations by AIJ

Factors influencing performance

- Corrosion of steel
- Resistivity for leakage of water
- Scenery

Performance:
- Serviceability
- Durability
- Beauty appearance
- Security feeling
### 3.2 Limit Values for Control Target

**For example**

<table>
<thead>
<tr>
<th>JSCE</th>
<th>0.005C (C: concrete cover): Limit value of crack width for preventing corrosion of steels</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIJ</td>
<td><strong>Performance</strong></td>
</tr>
<tr>
<td></td>
<td>Resistivity of leakage of water</td>
</tr>
<tr>
<td></td>
<td>Durability under normal environment</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Limit Values for Control Target

Limit value for preventing DEF cracking

Verification index

Maximum temperature in concrete member

Limit value

Basically 70°C, 65°C or 80°C depending on conditions

Verification is conducted in cases under water contact conditions continuously or intermittently

Bases of limit values are explained later in this session
### 3.2 Limit Values for Control Target

Limit values of maximum temperature in concrete member

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°C</td>
<td>● Basic condition</td>
</tr>
<tr>
<td>80°C</td>
<td>● High early strength or ordinary portland cement is used with total alkali and SO(_3) content of 3.0 kg/m(^3) or less and 9.0 kg/m(^3) or less, respectively.</td>
</tr>
<tr>
<td></td>
<td>● Either moderate heat portland cement or low heat portland cement is used.</td>
</tr>
<tr>
<td></td>
<td>● Any of blast-furnace slag cement class B, class C and fly ash cement class C is used, or the replacement ratio of cement by fly ash or ground granulated blast-furnace slag for concrete follows the specifications of the above blended cements when those admixtures are used, or silica fume at a mixture ratio of 10% or over is used for concrete.</td>
</tr>
<tr>
<td>65°C</td>
<td>● Alkali and SO(_3) content in concrete is 4 kg/m(^3) or higher and 17 kg/m(^3) or higher, respectively.</td>
</tr>
</tbody>
</table>
3.2 Limit Values for Control Target

Verification of maximum temperature in concrete member for preventing DEF cracking

In principle, maximum temperature should be predicted precisely

There may be many cases that maximum temperature does not reach 70°C or 80°C clearly depending on type of cement, placing temperature, unit cement content, member thickness, verification position of maximum temperature, etc.

Apply experience based verification ➔ Section 4.5
Experience based verification

Target structure

- Specifications for materials, design and construction works
- Conditions of environment and climate

Existing structures; achieving control target

- Specifications for materials, design and construction works
- Conditions of environment and climate

almost the same

Control target of target structure is judged to be satisfied.
3.3 Methods of Controlling Thermal Cracks

When preventing thermal cracking

Methods for Controlling Volumetric Change in Concrete
Methods to Reduce External Restraints

When controlling thermal crack width

Reduce induced stress by the above methods, furthermore proper arrangement of reinforcement, if necessary
3.3 Methods of Controlling Thermal Cracks

<table>
<thead>
<tr>
<th>Category</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>To control temperature rise in concrete</td>
<td>Use of cements with low heat of hydration</td>
</tr>
<tr>
<td></td>
<td>Use of admixtures</td>
</tr>
<tr>
<td></td>
<td>Reduction of unit cement content</td>
</tr>
<tr>
<td></td>
<td>Lowering materials’ temperature</td>
</tr>
<tr>
<td></td>
<td>Times of day and seasons for concrete placement</td>
</tr>
<tr>
<td></td>
<td>Placing methods of concrete</td>
</tr>
<tr>
<td></td>
<td>Curing methods</td>
</tr>
<tr>
<td>To use materials to reduce shrinkage strain</td>
<td>Materials with lower thermal expansion coefficient</td>
</tr>
<tr>
<td>in concrete</td>
<td>Use of expansive additives</td>
</tr>
<tr>
<td>To reduce external restraints</td>
<td>Crack control joint</td>
</tr>
</tbody>
</table>
3.3 Methods of Controlling Thermal Cracks

Design of Crack Control Joint

- ○ Crack generated in crack control joint.
- × Crack appeared only between the joints.
- △ No crack was observed.

Crack Control Joint
See Section 5.7.8

![Diagram showing section reduction ratio and crack control joint design.](image-url)
3.3 Methods of Controlling Thermal Cracks
Arrangement of reinforcing steels

First, reduce temperature rise

Then, arrange reinforcing steels, if necessary
3.4 Methods for Preventing DEF Cracking

**Methods for Preventing DEF Cracking**

- **Method for controlling maximum temperature in concrete**
  - DEF cracking does not occur if maximum temperature in concrete is lower than the limit value; 70°C or 80°C.

- **Measure for concrete members to avoid contact with Water**
  - DEF cracking never occur if water is not supplied to a concrete structure.
### 3.4 Methods for Preventing DEF Cracking

#### Water exposure conditions

<table>
<thead>
<tr>
<th>Exposure to water</th>
<th>Exposure condition with water</th>
<th>Level of exposure to water</th>
<th>Measures against DEF cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>No exposure</td>
<td></td>
<td>Dry or moderate humidity condition, etc.</td>
<td>Unnecessary</td>
</tr>
<tr>
<td>Exposure</td>
<td>Intermittent</td>
<td>Dry-wet cycling, high humidity condition, etc.</td>
<td>Necessary</td>
</tr>
<tr>
<td></td>
<td>Continuous</td>
<td>Permanent immersion, ponding at surface, tidal zone, water saturated condition, etc.</td>
<td>Necessary</td>
</tr>
</tbody>
</table>
3.4 Methods for Preventing DEF Cracking

Methods for controlling maximum temperature in concrete due to heat of hydration of cement

Controlling Volumetric Change in Concrete — Methods to control temperature rise in concrete

<table>
<thead>
<tr>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of cements with low heat of hydration</td>
</tr>
<tr>
<td>Use of admixtures</td>
</tr>
<tr>
<td>Reduction of unit cement content</td>
</tr>
<tr>
<td>Lowering materials’ temperature</td>
</tr>
<tr>
<td>Times of day and seasons for concrete placement</td>
</tr>
<tr>
<td>Placing methods of concrete</td>
</tr>
<tr>
<td>Curing methods</td>
</tr>
</tbody>
</table>

Same methods as applied for controlling thermal cracking can be applied for preventing DEF cracking.
3.4 Methods for Preventing DEF Cracking

Methods for preventing water penetration into concrete structure

Cover concrete surface by proper material for protecting water penetration

or

Construct water shielding structure for target structure

For example, a construction method using steel liner or another structure for water shielding
Thank you very much for your kind attention!