PROVISIONS AGAINST THERMAL AND DRYING SHRINKAGE CRACKING IN CONSTRUCTION OF PRESTRESSED CONCRETE BRIDGE

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AGENDA

1. Introduction & Summary of Construction

2. Provisions for Thermal Cracking

3. (Provisions for Drying Shrinkage Cracking)

4. Conclusions
Prestressed concrete bridge

In winter, the lowest temperature < 0 °C

During the in-service period, the de-icing agent is planned to be used.

If the concrete structure has some cracks, the accelerated concrete deterioration becomes an issue.

Technical challenges was to control the early age cracking.
Introduction & Summary of Construction

Construction Outline

Type: 5 and 9 span of continuous PC box-girder bridges
Erection method: Cantilever, Fixed falsework
Introduction & Summary of Construction

Cantilever Erection

<table>
<thead>
<tr>
<th>Side Closure</th>
<th>Cantilever</th>
<th>Column Capital</th>
<th>Cantilever</th>
<th>Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.473</td>
<td>35.000</td>
<td>12.000</td>
<td>35.000</td>
<td>2.962</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typical longitudinal section

In the Spans

Column Capital

Typical cross sections
Introduction & Summary of Construction

Contents of this report

This report explains the controlling methods of the early age cracking that had been adopted for the bridge construction of the cantilever erection.

The early age cracking:
Thermal cracking (and Drying shrinkage cracking)
Provisions for Thermal Cracking

Objective

Flow diagram of verification (Ordinary)

1. Requirements and Constraints
   - Targets of Thermal Crack Control
     (Minimum Limit Values of Thermal Cracking Index)
     - 3D-FE Analysis for First Construction
     - Verification
       (Satisfy the Limit Values?)
       - Yes: Construction
       - No: Consideration of Additional Provisions

2. Standard Construction Methods and Material
   - Additional verification
Provisions for Thermal Cracking

Objective

Flow diagram of verification (This Construction)

- Verification (Satisfy the Limit Values?)
  - Yes
    - First Construction
      - Thermal Fitting Analysis
        - 3D-FE Analysis for the Following Constructions
          - Verification (Satisfy the Limit Values?)
            - Yes
              - Remaining Constructions to Follow
            - No
              - Consideration of Additional Provisions

- Additional verification
  - Measurement of Concrete Temperature
  - Confirmation of Each Matter Value for Property
# Objective

## Target values of thermal cracking index

<table>
<thead>
<tr>
<th>Part</th>
<th>Minimum limit values of cracking index</th>
<th>Rough indication of cracking index in [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper slab, Bridge end</td>
<td>1.75</td>
<td>When thermal cracking is required to be prevented (Thermal cracking probability: 5%)</td>
</tr>
<tr>
<td>Under slab, Web</td>
<td>1.45</td>
<td>When thermal cracking is required to be limited as much as possible (Thermal cracking probability: 25%)</td>
</tr>
</tbody>
</table>

[1]: Standard Specification for Concrete Structures -2007
# Provisions for Thermal Cracking

## Objective

### List of provisions against thermal cracking

<table>
<thead>
<tr>
<th>Part</th>
<th>Change of cement type</th>
<th>Expansive additive</th>
<th>Insulated curing</th>
<th>Concrete cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st lift</td>
<td>○</td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2nd lift</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Cantilever</td>
<td>○</td>
<td></td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Closure</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Side closure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st lift</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>2nd lift</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
# Provisions for Thermal Cracking

## Cement type and Expansive additive

Different types of binders for each part

<table>
<thead>
<tr>
<th>Part</th>
<th>Original cement type</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column capital</td>
<td>HPC*¹</td>
<td>MPC*²</td>
</tr>
<tr>
<td>Cantilever</td>
<td>HPC*¹</td>
<td>OPC*³</td>
</tr>
<tr>
<td>Closure</td>
<td>HPC*¹</td>
<td>OPC<em>³+EX</em>⁴</td>
</tr>
<tr>
<td>Side closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1ˢᵗ lift</td>
<td>HPC*¹</td>
<td>OPC*³</td>
</tr>
<tr>
<td>2ⁿᵈ lift</td>
<td>HPC*¹</td>
<td>OPC<em>³+EX</em>⁴</td>
</tr>
</tbody>
</table>

*¹: High-early-strength Portland Cement (HPC)  
*²: Moderate-heat Portland Cement (MPC)  
*³: Ordinary Portland Cement (OPC)  
*⁴: Expansive Additive (EX)
## Provisions for Thermal Cracking

### Insulated curing

<table>
<thead>
<tr>
<th>Part</th>
<th>Method of curing</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge face (In the spans)</td>
<td>Wet mat and Insulated mat</td>
<td>From casting to the assurance age of strength</td>
</tr>
<tr>
<td>Bridge face (On the piers)</td>
<td>Wet mat and Insulated mat</td>
<td>From casting to the assurance age of strength (The time when the insulated mat was installed after the temperature inside the concrete reached the peak)</td>
</tr>
</tbody>
</table>
Provisions for Thermal Cracking

Cooling concrete

< Cooling concrete with liquid nitrogen >

Jet nozzle

Agitator-body
Truck

Scaffolding for jet

Tank lorry with liquid nitrogen
# Provisions for Thermal Cracking

## Cooling concrete

< Cooling concrete with liquid nitrogen >

Management temperature of cooling

<table>
<thead>
<tr>
<th>Part</th>
<th>Maximum limit concrete temperature at the casting</th>
<th>Management temperature after injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st lift</td>
<td>30°C</td>
<td>29°C</td>
</tr>
<tr>
<td>2nd lift</td>
<td>26°C</td>
<td>25°C</td>
</tr>
</tbody>
</table>

Quantity of LN$_2$ necessary to reduce concrete of 1 m$^3$ by 1 °C was 14.9 kg/m$^3$ °C
Provisions for Thermal Cracking

Cooling concrete

< Air-cooling with the use of deflection tube >

Branched duct  Deflection tube  Duct  Fan
## Provisions for Thermal Cracking

### Effect of provisions

Cases of 3D-FE analysis in advance for the column capital part

<table>
<thead>
<tr>
<th>Case</th>
<th>Conditions of analysis model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard construction only with OPC</td>
</tr>
<tr>
<td>2</td>
<td>Case 1 with MPC</td>
</tr>
<tr>
<td>3</td>
<td>Case 2 with insulated curing</td>
</tr>
<tr>
<td>4</td>
<td>Case 3 with cooling with LN$_2$ and air-cooling</td>
</tr>
</tbody>
</table>
Provisions for Thermal Cracking

Effect of provisions

< Case 1 >
Standard construction only with OPC

Target values
2nd lift : 1.75
1st lift : 1.45

< Case 2 >
Case 1 with MPC

The Minimum index: 0.97
The Minimum index: 0.87

The Minimum index: 1.17
The Minimum index: 1.43
Provisions for Thermal Cracking

Effect of provisions

< Case 3 >
Case 2 with insulated curing

Target values
2nd lift: 1.75
1st lift: 1.45

< Case 4 >
Case 3 with LN$_2$-cooling and air-cooling

The Minimum index: 1.28
The Minimum index: 1.42

The Minimum index: 1.83
The Minimum index: 1.54
Provisions for Thermal Cracking

Effect of provisions

3D-FE Analysis for Initial Construction

- Verification (Satisfy the Limit Values?)
  - Yes: First Construction
  - No: Consideration of Additional Provisions

First Construction

Thermal Fitting Analysis

3D-FE Analysis for the Remaining Constructions to Follow

- Verification (Satisfy the Limit Values?)
  - Yes: Remaining Constructions to Follow
  - No: Consideration of Additional Provisions

Result of thermal analysis (Case 4)

- Measurement of Concrete Temperature
- Confirmation of Each Matter Value for Property

○: Measurement point
Provisions for Thermal Cracking

Effect of provisions

< Effect of cooling with LN$_2$ >  < Effect of air-cooling >

![Graphs showing temperature inside concrete over days for cooling with LN$_2$ and air-cooling.]
Conclusions

It was confirmed that the provisions against the thermal cracking were effective.

It was confirmed that the provision to the cement type with less total heat generation due to the hydration reactions was effective especially in the 1st lift. And reducing temperature of concrete such as cooling was effective in the 2nd lift for controlling the thermal crack at the column capital. The values of thermal properties calculated after the fitting analysis were almost similar to one of the prior verifications.