Chapter 5

Construction Works

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5.1 Construction Work

(1) Construction works of mass concrete shall be executed based on the control plan decided in the design stage so that the effects of measures for thermal cracking and DEF cracking are sufficiently developed.

(2) An execution plan shall be made so that the control targets for thermal cracking and DEF cracking can be achieved and a quality control plan shall be made so that a feasibility of the control plan can be confirmed.

[Commentary (2)]
Execution plan must include followings such as,

- all aspects of concrete production, transportation, placement, compaction, treatment of joints
- size of one block of concrete placing, curing method, and the time of form removal
- To confirm if the planned items are realized in the actual work as necessary by
  - Concrete strength
  - Temperature
  - Stress and strain
5.1 Construction Work

(3) When it is anticipated that attaining the target of thermal crack control will be difficult due to differences between the actual environmental or construction conditions and the assumptions at the time of making the control plan, the thermal crack control plan shall be reviewed and revised if necessary.

(4) Execution and quality control shall be implemented in accordance with the execution plan and the quality control plan that have been formulated beforehand.

[Commentary (3)]

Modification in the control plan to be implemented such as,

- design of construction joint and reinforcement arrangement
- selection of materials
- production of concrete
- execution method
- quality control
5.1 Construction Work

(5) Temporary measures shall be executed and other execution and quality control plans shall be investigated and reflected to later construction works when it is judged that it is difficult to achieve the targets for controlling thermal cracking as well as preventing DEF cracking at the execution stage. But the original plans for controlling thermal cracking and preventing DEF cracking shall be reinvestigated when the execution plan is checked and it is judged that achievement of the design target may be difficult.

[Commentary (5)]
An emergency measures should be taken and the execution plan should be reviewed.
(a) Examples to be difficult to achieve the target of controlling cracking.
   □ Inside temperature of concrete member is higher than predicted
   □ Surface temperature of concrete is considerably low/high than predicted
   □ Placing temperature of concrete is high more than expected
(b) Example of emergency measures
   □ To adjust curing period, to reduce lift thickness, span length, and to implement a test of adiabatic temperature rise for reconfirmation
   □ To add or to remove insulation material, to reinvestigate duration of insulation curing
   □ To shield transportation pipes from sunlight, to cool by spraying water
5.1 Construction Work

(6) Detailed contents of execution and quality control shall be recorded and kept for either longer one of period stipulated by quality management plan or period stipulated by specification of contracting agency or standard of society.

[Commentary (6)]

✓ It will be used to investigate the causes and reasons.
✓ Also it will be useful for working out a rational control plan for similar execution work in future
5.2 Execution Plan and Quality Control Plan

5.2.1 Execution Plan

(1) The execution plan for the mass concrete construction shall include a detailed implementation plan for each construction stage that takes into consideration the environmental conditions at the time of execution.

(2) The execution plan shall include measures against unexpected rapid climate changes beyond assumptions during execution, as well as criteria to determine whether these measures should be implemented.

(3) Construction instructions shall be prepared to ensure execution in accordance with the execution plan.

[Commentary]
(1) To control thermal cracking and prevent DEF cracking at design stage, a comprehensive investigation should be carried out in execution stage. See Reference Materials 19, 22, 23, 24.
(2) It is important to consider the measures against unexpected rapid climate change when formulating the execution plan, because the measures taken on the execution day are limited.
(3) As each execution item must be accomplished without fail in order to attain the target, specific work instructions must be prepared.
5.2.2 Quality Control Plan

(1) The **quality control plan** for mass concrete construction **shall include a detailed control plan** for each construction stage.

(2) The items in the quality control plan shall be determined taking into consideration the **degree of importance or performance requirements** of the structures.

(3) **Quality control instructions** shall be prepared to ensure that quality control will be carried out in accordance with the quality control plan.

[Commentary]
(1) A detailed control plan includes the type of cement, unit cement content, concrete temperature at acceptance, timing of removal of forms, specifications for insulation material, and removal time of insulation material. See Reference Materials 18.

(2) For important structures requiring watertightness, airtightness, or special durability, it is necessary to implement quality control with instrumental measurement in addition.

(3) To implement (1) and (2), it is necessary to designate a person in charge of quality control and to formulate the details of control work for each control items (time, frequency, etc.)
5.3 Materials

(1) **Materials stipulated in control plan** such as cement, admixtures, aggregates, reinforcing steel and other reinforcing materials **shall be used** in principle.

(2) Control of thermal stress and thermal cracking and prevention of DEF cracking **shall be reexamined when** the cement, admixtures and/or aggregates stipulated in the control plan **are changed**.

(3) Control of thermal crack width **shall be reexamined when** the quantity, size and/or arrangement of reinforcing steel stipulated in the control plan **are changed**.

【Commentary】

When use blended cement with large amount admixture such as blast furnace slag or fly ash, we should verify its quality and physical properties.
5.4 Mixture Proportions

(1) The *mixture proportions* of concrete shall be as determined in the control plan in principle, and they shall be selected taking into account the required workability, strength and durability.

(2) If the mixture proportions specified in the control plan need to be changed because they do not satisfy the required workability, strength and durability, then thermal stress, thermal cracking and DEF cracking shall be reinvestigated.

**Commentary**

Necessitating unit cement content to be increased by 5% or more, thermal stress, thermal cracking and DEF cracking should be reexamined.
5.5 Production of Concrete

(1) The temperature of fresh concrete after mixing shall be controlled so that the temperature at placement stays below the value determined in the control plan.

(2) When concrete materials and fresh concrete are to be actively cooled, the cooling method stipulated in the control plan shall be implemented appropriately.

【Commentary】
Fresh concrete temperature should be controlled by following methods
a. Protect aggregate from direct sunlight at storage facility
b. Reject hot cement per purchase plan
c. Spray water on coarse aggregate stockpiles
d. Use cool ground water for mixing
e. Produce and place concrete in nighttime or early morning
### 5.6 Ready-Mixed Concrete

(1) When ready-mixed concrete is used, the required properties of the resulting concrete shall be verified to achieve the control targets for thermal cracking and DEF cracking.

(2) If it is difficult to ensure the concrete quality determined to achieve the control targets for thermal cracking and DEF cracking, the specifications of the concrete shall be changed in consultation with the concrete supplier and the quality of the resulting concrete shall be verified.

#### Commentary

Type of cement, upper limit of unit cement content, concrete temperature at unloading, age to guarantee nominal strength, as well as usual specified items should be discussed with supplier and set as purchase specifications.
5.7 Execution

5.7.1 General

(1) Execution shall be implemented in accordance with the execution plans and execution instructions.

(2) When the progress of execution or securing the required quality of the structure under construction is hindered because the situation/conditions exceed preliminary assumptions, emergency measures shall be taken.

[Commentary](2)

emergency measures such as adding curing materials, extending the curing period, or adding crack control reinforcement may be considered.
(3) Execution shall be implemented after the results of the quality control up to the present are reflected in the execution plan and execution instructions for the next execution processes.
(4) Execution-related data shall be recorded and preserved.

5.7.2 Placing Blocks and Lift Height

(1) Mass concrete block sizes, lift heights, joint position and structure, as well as the construction of joints and joint time interval shall be determined appropriately based on the control plan.
(2) When there are significant differences in the above compared with the original control plan, examination of thermal stress, thermal cracking and DEF cracking shall be implemented.
5.7.3 Construction Joints

(1) In the execution of horizontal construction joint, surface treatment of the existing layer of concrete, such as removal of laitance, chipping, etc., shall be implemented.

(2) The execution of vertical construction joints shall be implemented so as not to impair the intended functions of the structure.

[Commentary](1)
The time suitable for conducting surface treatment depends on the properties of concrete and the weather conditions.
ex:
Construction joints can be made by retarding the setting of the surface concrete by spraying a set-retarding agent on the surface of the concrete, and washing out the laitance with high-pressure water on the next day.
5.7.4 Transportation and Placing of Concrete

(1) In order to keep the concrete temperature at placement below the temperature specified in the control plan, temperature rise during transportation shall be controlled.

(2) Fresh concrete shall be transported quickly using a method that causes as little material segregation as possible, and concrete within one block shall be continuously placed and compacted.

[Commentary](2)

- Mass concrete construction huge amount of concrete with a small amount of cement and low slump
- As for pumping, it is necessary to formulate a plan based on proper evaluation of pumpability, pipe length, pipe diameter, piping method, and so on, based on consideration of the fact.
(3) When concrete is placed in more than one layer in one block, the compaction shall be carried out so as to intermingle the concrete in the upper and lower layers.

(4) The vertical distance between the tip of a chute, the tip of a concrete pumping pipe, or the outlet of a concrete hopper to the placing surface of concrete shall be less than 1.5 meters in principle.

[Commentary](3)
In order to prevent the occurrence of cold joints, the construction procedure shall be determined taking into consideration the area of each block, the concrete supply speed, and the time interval of placement.
5.7.5 Compaction and finishing

(1) For concrete compaction, internal vibrators are used in principle. The concrete is not properly compacted, it may become initial point of cracking.

(2) Cracks that occur on the concrete surface after finishing and before the start of hardening of concrete shall be repaired by tamping or refinishing.

[Commentary]

(1) The low-slime concrete is often adopted, the internal vibrators are used for compaction in principle. The concrete is not properly compacted, it may become initial point of cracking. The concrete is not properly compacted, it becomes ununiform and may become initial point of cracking.

(2) A retarder may be used as a way to support increases in the time interval of placement. However, bleeding and subsidence cracks may occur. Attention should be paid to the repair of subsidence cracks, for example due to inadequate tamping.
5.7.6 Curing

(1) Placed concrete shall be cured adequately, taking care to protect it from direct sunlight, wind, rapid drying as well as abrupt drops in ambient temperature.

(2) Surface cracking due to internal restraint should be prevented by appropriate curing in principle.

[Commentary]
(1) Care should be taken not to lower the surface temperature rapidly even after the concrete reaches its peak temperature and to let the concrete temperature and the ambient temperature come to equilibrium as slowly as possible.

(2) This guidance is based on the view that surface cracking due to internal restraint can be prevented by appropriate curing.
5.7.6 Curing

(3) When insulated curing is conducted, the kind of heat insulating materials and start/end times of curing shall be determined adequately.

(4) During curing of concrete, it shall be confirmed whether curing is appropriately implemented according to the execution plan.

(5) If it is judged the cracking control target will not be achieved owing to weather changes that exceed preliminary assumptions, appropriate measures shall be taken.

[Commentary]
(3) Insulated curing is effective to mitigate thermal stress due to internal restrain. It is necessary to carefully consider the start time of insulated curing because it may raise the temperature. In addition, the temperature at the surface of the concrete may suddenly decrease toward the end of insulated curing. Therefore, it is desirable to confirm the start/end times of insulated curing through analysis.
5.7.6 Curing

Photo C5.7.2 Example of sheet curing

Photo C5.7.3 Example of mat curing

Photo C5.7.4 Curing with foamed polyethylene sheet containing air bubble

Photo C5.7.5 Example of moisture curing with high heat insulating material
5.7.7 Form

(1) The materials used for forms shall be selected taking into consideration the type of structure, its shape, the mixture proportions of concrete and meteorological conditions.

(2) Proper measures shall be taken so that thermal cracking due to internal restraint does not occur at form removal.

[Commentary]

(1) In order to reduce the temperature difference between outside and inside of concrete, it is advantageous to use wooden forms. On the other hand, the use of wooden forms increases the concrete temperature and may induce thermal cracking when the structure is a wall type with member thickness of less than approximately 1.0 m.

(2) Removing formwork may cause cracking due to sudden cooling and drying of the concrete surface. To prevent this, Formwork can be safely removed when the difference between the internal temperature of the concrete and the outside temperature is 20°C or less. Further method such as delaying the removal of the formwork, covering the concrete with a sheet following formwork removal, or using a membrane curing compound may be used.
5.7.8 Crack control joint (1)

Structure and shape of crack control joint shall be appropriately determined so that a crack occurs surely at the joint and waterproof performance and durability of a structure are not damaged.
5.7.8 Crack control joint (2)

Structure and shape of crack control joint shall be appropriately determined so that a crack occurs surely at the joint and waterproof performance and durability of a structure are not damaged.
5.7.9 Pre-Cooling

A method of pre-cooling shall be selected taking into consideration its cost performance, **safety**, applicability and production capacity of cooling equipment.

- Cooling method using liquid nitrogen gas
  - Caution!: 
    - Oxygen concentration is decreases. 
    - Visibility is reduce.
5.7.10 **Pipe cooling**

(2) Cooling pipes shall be *properly selected* taking into consideration the cooling effect and workability.
(3) Before the concrete is placed, the cooling pipes shall be *securely fixed* and thoroughly checked for water tightness.

**Material for cooling pipes**
Thin electric resistance welded steel pipes, carbon steel pipes for piping, sheath tubes, polyethylene pipes.

**At a construction joint**
See Fig. C5.7.9.
5.8 Quality control

5.8.1 General

(1) Quality control shall be implemented in accordance with the quality control documents.

(2) When the control target for thermal cracking or DEF cracking is judged not to be attained because the monitored value for control exceeds the standard value, countermeasures shall be devised accordingly and quickly implemented.

(3) Whether or not thermal cracking or DEF cracking has occurred, and whether crack widths are within the allowable range shall be confirmed after construction.

(4) The information collected for quality control shall be recorded and stored.

5.8.2 Control of concrete temperature

(1) The concrete temperature at placing shall be confirmed not to exceed the control value.

(2) The concrete temperature after placing shall be controlled to lie on the safe side of the control value set out in accordance with the temperature history predicted when making the control plan.
5.8.3 Control of curing
(1) Attention shall be paid not to allow thermal cracks caused by internal restraint to take place when the form is removed.
(2) If the results of measurement during the curing period or the appearance of thermal cracks do not compare favorably with the initial prediction, the cause shall be investigated and appropriate measures shall be taken.
(3) Throughout the cooling operation, the temperatures of the concrete and cooling water as well as the flow rate or velocity of the cooling water shall be measured.

5.8.4 Control of structure
(1) When curing is brought to an end, the concrete temperature shall be confirmed to have declined to near the ambient temperature, and then the patterns of thermal cracking, if any, shall be investigated.
(2) If the occurrence of thermal crack shows a large discrepancy with the results of prior predictions and this might impair the required performance of concrete structures, root cause analysis shall be carried out and appropriate repair shall be performed.
Estimation of adiabatic temperature rise by back analysis using simple insulating container

In this adiabatic temperature rise test by the back analysis, temperatures of concrete are measured using the simple insulating container whose thermal characteristics have been determined, and the adiabatic temperature rise is calculated by performing the back analysis by FEM (finite element method) applying the measured data.

This test method does not require large test equipment with a temperature control device and its calibration.
Method for estimating adiabatic temperature rise by back analysis

1. The increment ($\Delta Q(t_{\text{time}_i})$) from the adiabatic temperature rise is assumed.
2. $\Delta Q(t_{\text{time}_i})$ is varied multiple times, and the temperature analysis is performed with each increment.
3. The temperature data obtained from the temperature analysis and the concrete test sample, the sum of square of the difference between the actual measured values and the analyzed ($J_{\text{time}_i}$) is calculated.
4. $\Delta Q(t_{\text{time}_i})$ that minimizes the sum of squares ($J_{\text{time}_i}$) is determined ($J_{\text{time}_i}$ (min))
5. The same estimation for the next step ($t_{\text{time}_{i+1}}$) is repeated then the adiabatic temperature rise can be calculated.
Fig. 8 shows the adiabatic temperature rise calculated by the back analysis corresponding to each specific heat when pouring temperature is 20°C. The calculated result with specific heat of 1.05 (kJ/kg°C) has a good agreement with the adiabatic temperature rise measured by using the test equipment.

![Fig. 8 Adiabatic temperature rise estimated by the back analysis](image-url)
RF-20: Estimation of adiabatic temperature rise curve with mass-block test specimen

Mock-up specimen / Thermocouple location

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>$Q_\infty$ (°C)</th>
<th>$\gamma$</th>
<th>$h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-40</td>
<td>51.0</td>
<td>1.56</td>
<td>1.05</td>
</tr>
<tr>
<td>S-50</td>
<td>55.0</td>
<td>2.00</td>
<td></td>
</tr>
</tbody>
</table>

$Q(t) = Q_\infty (1 - e^{-\gamma(t-h)})$

$\eta$: heat transfer coefficient for polystyrene foam + plywood (W/m²°C)

- Mock-up specimen (1m x 1m x 1m) with 5nos of thermocouples, 50mm thk polystyrene foam, plywood panel is provided
- Required characteristic properties are estimated by the fitting.
- **Based on this parameters, curing procedure was proposed.**
Provision of Crack Control Methods based on Actual Temperature Monitoring Record

General

- Sahara Desert in Algeria
- Rotary machinery foundation – A crack is concerned by Client
- Continuous concrete casting is not feasible because fresh concrete cannot be produced under stable condition.
- The requirement is only to maintain temperature difference between center and near surface of concrete within 20°C.

Temperature was monitored at first block by thermo-couples

The result was out of the control range. Thus, the execution plan has to be revised for second block pour.
Analysis

Step 1: Adiabatic temperature rise was identified from back analysis of first block.

Step 2: Curing methodology was studied in the thermal analysis. (ASTEA MACS)

By improving thermal property of insulation form, the differential temperatures could be reduced within the control range.

Step 3: Thermal insulation performance was verified in second block pour.

For second block, the actual concrete temperatures were recorded to verify the thermal insulation performance. The differential temperatures were restricted within 20°C.
### Specification and Performance Requirements

<table>
<thead>
<tr>
<th><strong>Design strength</strong></th>
<th>40N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum of effective water-binder ratio</strong></td>
<td>40% (Set to 38% in consideration of manufacturing variation)</td>
</tr>
</tbody>
</table>

**Concrete temperature regulation**
- Maximum temperature difference between the mean temperature of the newly cast element ≤ 15°C
- Maximum temperature difference between the mean temperature of the element and the temperature in the surface of the element ≤ 15°C
- Maximum temperature ≤ 65°C
- Crack risk ≤ 0.7 (Crack risk is reciprocal number of the crack index, Crack index ≥ 1.43)

**Cement type**
- CEMⅢ/B (Substitution ratio of mineral admixtures 66～88%) or CEM I
- In case of CEM I, replaceable of fly ash ≤ 15% and silica fume ≤ 5%

Reference 22: Control of thermal stress cracks based on Mock-up construction (in Republic of Turkey.)
JCI Guidelines for Control of Cracking of Mass Concrete 2016

Mock-up construction

Temperature measuring position

Measurement result
Concrete temperature based on Mock-up examination

Analysis result
Based on analyzing these measurement results, in order to secure the crack risk of 0.7 or less even under the construction conditions of the whole year.
RF-23: Case study where the requirements are not given

- No specific design requirements for crack control for mass concrete
- Models are categorized into several groups by mix design, member size.
- **Construction and curing plan was provided based on analysis results.**

<table>
<thead>
<tr>
<th>thickness</th>
<th>Temp@ puring</th>
<th>curing condition</th>
<th>min. cracking index</th>
<th>max. crack width (mm)</th>
</tr>
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<tbody>
<tr>
<td>&lt;1.0m</td>
<td>32°C</td>
<td>plywood</td>
<td>1.04</td>
<td>0.23</td>
</tr>
<tr>
<td>&lt;1.2m</td>
<td>24°C</td>
<td>only</td>
<td>1.00</td>
<td>0.24</td>
</tr>
<tr>
<td>&lt;1.5m</td>
<td></td>
<td>plywood &amp; insulation</td>
<td>1.37</td>
<td>0.12</td>
</tr>
<tr>
<td>&lt;2.0m</td>
<td></td>
<td></td>
<td>1.2</td>
<td>0.18</td>
</tr>
</tbody>
</table>
### Reference Material 24  Pipe Cooling Method

#### Implementation methods and important Issues

| (1) Pipe diameter and material | Diameters: 27.6~80mm  
Material: Galvanized metallic water pipe (SGPV)  
Carbon steel pipe (SGP)  
Thin electric resistance tube  
PC tendon sheath pipe  
polyethylene pipe |
<table>
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<tbody>
<tr>
<td>(2) Pipe interval</td>
<td>50~100cm</td>
</tr>
<tr>
<td>(3) Pipe direction</td>
<td>Horizontal, Vertical</td>
</tr>
<tr>
<td>(4) Pipe length</td>
<td>100~150m/coil</td>
</tr>
</tbody>
</table>
| (5) Temperature of cooling water | pot water, industrial water: 15~20°C  
block ices or a chiller: lower than 15°C |
| (6) Amount of water flow     | 10 to 20ℓ/inch pipe.                            |
| (7) Water input duration     | a few days to a week.                           |
Reference Material 24  Pipe Cooling Method

Effectiveness (example of applying)

Fig. 3.1 Example of structure applied pipe cooling (PC Girder)

Photo 3.1 Distribution of cooling pipe

Photo 3.2 Water chilling facility
Reference Material 24: Pipe Cooling Method

Temperature difference means the difference between measured temperature at upper/bottom surface and at inside of a member.

Fixed values for control:

\[ \Delta T_{\text{meas,up}} \] at upper surface
\[ \Delta T_{\text{meas,bot}} \] at bottom surface

Fig. 3.4 Temperature controlling result and crack index calculated from measured effective stress [5][6]
Thank you for your kind attention.