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Indian Standard

TEMPERATURE CONTROL OF MASS CONCRETE FOR DAMS — GUIDELINES

ICS 93.160

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Price Group 6

Dams (Overflow and Non-overflow) and Diversion Works Sectional Committee, RVD 9

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Dams (Overflow and Non-overflow) and Diversion Works Sectional Committee had been approved by the River Valley Division Council.

Mass concrete structures undergo volumetric changes with time after the placement of concrete. A rapid rise in the temperature of mass concrete takes place during the phase when the concrete mass is in plastic stage and undergoes hardening. After hardening, the concrete gradually cools due to effect of atmospheric temperature, which tends to subject the concrete to high tensile stresses. Cracking occurs in the concrete when these tensile stresses exceed the tensile strength of the concrete. This cracking is undesirable because it affects the water tightness, durability and appearance of hydraulic structures. The cracking tendency may be reduced to acceptable levels through appropriate design, construction and concrete placement procedures.

Temperature control is essential to (a) minimize volumetric changes and control the size and spacing of undesirable cracks and (b) facilitate completion of the structure during the specified construction period by increasing lift heights.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, should be rounded off in accordance with IS 2:1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

TEMPERATURE CONTROL OF MASS CONCRETE FOR DAMS — GUIDELINES

1 SCOPE

This standard mainly covers precooling methods adopted for temperature control in respect of mass concrete in dams. It also alludes to postcooling as the same is also adopted for overall temperature control.

2 NOTATIONS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each:

C = specific heat of concrete (J/kg°C),
D_2 = depth of lift (m),
h_d^2 = thermal diffusivity of concrete (m^2/hour),
K = thermal conductivity of concrete (J/m.h °C),
ρ = density of concrete (kg/m^3),
W = mass of effective cement content in unit volume of concrete (kg),
H = evolution of heat of hydration per unit mass of cement (J/kg),
T = adiabatic temperature rise in concrete (°C) at any time t,
T_0 = ultimate adiabatic rise of temperature in concrete (°C), and
t = time interval between successive lifts (h).

3 TERMINOLOGY

For the purpose this standard, the following definitions shall apply.

3.1 Adiabatic Temperature

It is the temperature attained by concrete due to heat of hydration without any gain or loss of heat from/ to the atmosphere.

3.2 Ambient Temperature

It is the atmospheric temperature at the dam site.

3.3 Coefficient of Thermal Expansion (α)

It is the change in linear dimension of a material per unit length per degree of temperature change.

3.4 Density (ρ)

It is the mass per unit volume of the material.

3.5 Placement Temperature of Concrete

It is the temperature of the mass concrete at the time of its placement at site.

3.6 Specific Heat (C)

It is the amount of heat required to raise the temperature of unit mass of concrete by one degree celsius.

3.7 Stable Temperature of Concrete

It is the temperature which a dam would achieve in course of time, say 8 to 10 years, or even more depending upon the reservoir water temperature and the mean annual ambient temperature.

3.7.1 *Stable Temperature at Downstream Face of Dam*

Ignoring the effect of daily or seasonal variation of surrounding temperature, the stable temperature of concrete near the downstream face can be assumed to be equal to the mean annual ambient temperature. This should be slightly modified if the downstream face of the dam is shadowed by surrounding hills.

3.7.2 *Stable Temperature at Upstream Face of Dam*

Since the upstream face will remain in contact with reservoir water, its stable temperature will be same as that of the reservoir water which may be taken as mean annual river water temperature.

3.8 Thermal Conductivity (K)

It is the rate of heat flow per unit area under a unit temperature difference between the two faces of material of unit length.

3.9 Thermal Diffusivity (h_d^2)

It is the index of the facility with which a material will undergo temperature change. It is a constant which determines the rate of temperature change in a homogeneous isotropic material when heated or cooled. Diffusivity can be defined as $h_d^2 = K/\rho C$.

4 TEMPERATURE RISE

4.1 General

Volume change and development of tensile stress in a concrete dam depend upon the temperature rise across the section of the dam. Newly placed concrete undergoes a rise in temperature due to the exothermic reaction of the cementing materials in the concrete. For final temperature control studies, the heat generation for particular concrete mix should be obtained by laboratory tests. The adiabatic temperature rise in the concrete relates to heat of hydration. The actual temperature rise in the concrete will be affected due to the flow of heat between the concrete in the body of the dam and that at the exposed faces of the dam. Temperature cracking in the mass concrete is related to the dimensions and shape of the concrete blocks, thickness of lifts, time interval between lifts and height differential between the blocks.

4.2 Factors Affecting Temperature Rise in Concrete

4.2.1 *Heat of Hydration of Cement*

Heat of hydration should be computed by conducting laboratory tests. Source of cement should be identified in advance and only one type of cement from the same source should be used in a dam. However, in absence of laboratory test results, heat of hydration for ordinary Portland cement may be assumed as 335 kJ/kg at 28 days.

4.2.2 *Specific Heat*

Specific heat of normal weight concrete varies only slightly with aggregate characteristics, temperature and other parameters. Values from 0.85 to 1.05 kJ/kg.°C are representative over a wide range of conditions and materials. This value may be adopted in the absence of laboratory test results.

4.2.3 *Thermal Diffusivity*

This is an index of the ease, or difficulty, with which concrete undergoes temperature change. For normal weight concrete where density and specific heat vary within narrow range, thermal diffusivity reflects the conductivity value. High diffusivity indicates greater ease in gaining or losing heat.

4.2.4 *Thermal Conductivity*

Thermal conductivity is a measure of the capability of concrete to conduct heat. The thermal conductivity varies with mineralogical characteristics of aggregate, moisture content, density and temperature of concrete. Values of thermal conductivity should be obtained by laboratory tests.

In the absence of laboratory tests, the values of diffusivity and thermal conductivity of concrete as given in Table 1 may be adopted for preliminary studies.

Table 1 Typical Values of Diffusivity and Thermal Conductivity of Concrete Made with Different Rocks

Coarse Aggregate	Diffusivity m^2/h	Thermal Conductivity J/mh°C
Basalt	0.003 0	7 534.8 to 7 576.66
Rhyolite	0.003 3	7 367.36 to 7 451.08
Granite	0.004 0	9 418.50 to 9 878.96
Dolomite	0.004 6	11 762.66 to 12 139.40
Limestone	0.004 7	11 302.20 to 11 637.08
Quartzite	0.005 4	12 641.72 to 12 767.30

4.2.5 The coefficient of thermal expansion for concrete is essentially constant over the normal temperature range, and tends to increase with increasing cement content and decrease with age. The main factors affecting the value of the coefficient of thermal expansion of concrete are aggregate type and moisture content; other factors such as mix proportion, cement type and age influence its magnitude to a lesser extent. Typical values of coefficient of thermal expansion of concrete using various aggregates is given in Table 2.

Table 2 Coefficient of Thermal Expansion of Concrete with Various Aggregates

Coarse Aggregate	Coefficient of Thermal Expansion/ °C
Quartzite	1.35×10^{-5}
Sandstone	1.04×10^{-5}
Basalt	0.83×10^{-5}
Limestone	0.58×10^{-5}
Granite	0.81×10^{-5}
Dolerite	0.77×10^{-5}
Gravel	1.22×10^{-5}

4.2.6 *Adiabatic Temperature Rise in Mass Concrete*

Newly placed concrete undergoes a rise in temperature due to exothermic reaction of the cementing material in the concrete. Hence, for temperature computations of mass concrete, certain parameters are required to be known or assumed. One of the important parameters is adiabatic temperature rise in concrete. This is required to determine the amount of heat generated for a specific period of time and effective cement content. Compound compositions and fineness of cement largely influence generation of heat.

Adiabatic temperature rise is governed by the law:

$T = T_0 (l\text{-}e^{-mt})$ where 'T_0' and 'm' are constants for a particular concrete.

4.2.6.1 For temperature rise, the specific heat of all the ingredients of concrete is the governing factor and the concrete absorbs the heat generated by the cement.

Heat generated by cement = Heat absorbed by concrete

$$WH = \rho.C.T_0$$

$$\text{or} \quad T_0 = \frac{WH}{\rho C}$$

4.2.6.2 *Placement temperature of concrete*

This is the temperature of the mass concrete at the time of its placement. This has to be predetermined in order to ensure that the maximum permissible temperature rise is not exceeded.

This can be computed by the formula:

$$T_p = \frac{0.22\,(T_{ca}.W_{ca}+T_{fa}.W_{fa}+T_c.W_c) + (T_f.W_f+T_w.W_w-79.6.W_i)}{0.22\,(W_{ca}+W_{fa}+W_c) + W_f + W_w + W_i}$$

where

T_p = placement temperature of concrete in °C,

T_{ca} = temperature of coarse aggregate at the time of mixing in °C,

T_{fa} = temperature of fine aggregate at the time of mixing in °C,

T_c = temperature of cement at the time of mixing in °C,

T_f = temperature in °C of free and absorbed moisture in aggregate which may be assumed to be same as that of aggregate unless otherwise specified,

T_w = temperature of batch mixing water in °C,

W_{ca} = dry mass of coarse aggregate in kg,

W_{fa} = dry mass of fine aggregate in kg,

W_c = mass of cement in kg,

W_f = mass of free and absorbed moisture in aggregate in kg,

W_i = mass of ice in kg, and

W_w = mass of batch mixing water in kg.

4.2.7 *Loss of Heat from the Mass Concrete After Placement and Net Temperature Rise*

4.2.7.1 The entire quantum of heat generated by hydration of cement does not go into raising the temperature of concrete. As heat is generated, there is also a loss to, or gain from, the atmosphere due to the difference in temperature between concrete and the atmosphere. For all practical purposes, it is sufficient to estimate the loss of heat from the exposed top surface of the lift. The heat loss from the vertical sides of the lift may be neglected. Also, the heat loss after successive lifts have been laid over the lift in question, is relatively small and can be neglected, that is, the heat lost from the exposed top surface during the interval between two lifts only is considered for estimating total heat loss. The loss of heat is calculated separately for the following three idealized conditions and then the total loss is obtained by summation of these losses:

a) Heat loss (q_3) from the exposed surface of a lift of depth D initially at temperature 0°C, exposed to 0°C at its upper surface and generating heat according to the law $T = T_0\ (1 - e^{-mt})$, if cast on an inert lift initially at 0°C. A lift is considered to be inert if the generation of heat by chemical action in the cement has ceased;

b) Heat loss (q_2) from the exposed surface of an inert lift of depth D initially at temperature θ_0 (where θ_0 = placement temperature – atmospheric temperature), exposed to 0°C at it's upper surface and cast on an inert lift at 0°C; and

c) Heat loss (q_1) from the exposed surface of an inert lift initially at 0°C, exposed to 0°C at it's upper surface and cast on an inert lift initially at temperature θ_1.

4.2.7.2 The first idealized condition assumes that the placement temperature of the concrete and the atmospheric temperature are the same that is 0°C and the lift is cast upon an inert lift initially at 0°C. The loss of heat as it is generated is given by the equation.

$$q_3 = \eta C\,\rho\,D\,T_0$$

or in terms of temperature equivalent of q_3,

$$T_3 = \eta\,T_0$$

where

q_3 = heat lost per unit area of the exposed surface in Joules, and

η = ratio of heat lost to the total heat generated.

The value of η can be determined from Fig. 1 after calculating the dimensionless quantities $D/\sqrt{4h_d^2 t}$ and mt where t is the time of exposure that is the interval between two lifts.

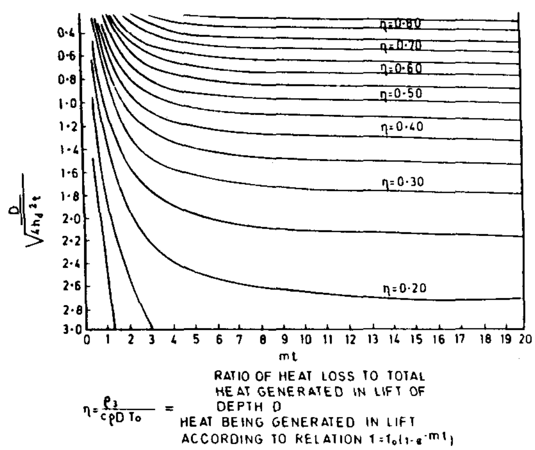

FIG. 1 PART OF TOTAL HEAT LOST FROM SURFACE OF LIFT

4.2.7.3 Under the second idealized condition, the heat loss due to the difference between the placement temperature and atmospheric temperature, which was assumed to be at 0°C in the first condition, is calculated. Since the heat loss due to internal heat generation is calculated under the first condition given in **4.2.7.1** (a), the lift is assumed inert, that is no internal heat generation is considered in the second condition. The heat loss from the exposed surface of an inert lift initially at a temperature q_0 above atmospheric temperature, cast on an inert lift initially at the same temperature as that of atmosphere, is given by:

$$q_2 = \frac{2K\theta_0\left[\sqrt{(t/h_d^2)} - I\right]}{\sqrt{\pi}}$$

or in terms of temperature equivalent of q_2

$$T_2 = \frac{q_2}{\rho . C . D}$$

$$\text{or} \quad T_2 = \frac{2h_d^2 \theta_0 \left[\sqrt{(t/h_d^2)} - I\right]}{D\sqrt{\pi}}$$

where

q_2 = heat loss per unit surface area of the lift, and

θ_0 = difference between placement temperature and atmospheric temperature and]

$$I = \int_0^t \frac{e^{-\frac{D^2}{4h_d^2 t}}}{\sqrt{4\,h_d^2\,t}}\, dt$$

I can be calculated from Fig. 2.

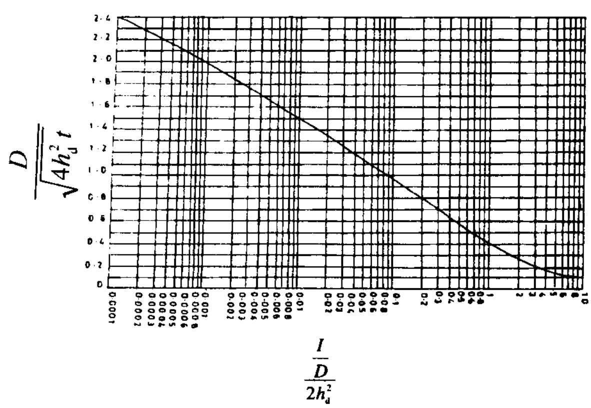

FIG. 2 PLOT OF $\dfrac{I}{\dfrac{D}{2h_d^2}}$ *Vs* $\dfrac{D}{\sqrt{4h_d^2\,t}}$

4.2.7.4 In the first and second idealized conditions, the lift is assumed to be cast on an inert lift which is at the same temperature as that of atmosphere. However, as at the end of the exposure period of the previous lift that is, at the time of placement of the new lift, some part of the total heat generated in the previous lift still remain unlost, the temperature of the previous lift is increased above atmospheric temperature due to this remaining heat. Therefore, some heat from the previous lift is lost through the exposed surface of the lift in question during the exposure period of this new lift. This heat loss is given by the equation:

$$q_1 = \frac{2K\theta_2 I}{\sqrt{\pi}}$$

or in terms of temperature equivalent of q_1

$$T_1 = \frac{2h_d^2\,\theta_2 I}{D\sqrt{\pi}}$$

where

q_1 = heat lost per unit area of the exposed surface,

I = same as given in **4.2.7.3**, and

θ_2 = difference of temperature between the temperature of the previous lift and the atmospheric temperature.

The temperature of the previous lift is calculated by subtracting the temperature loss during the exposure period from the total adiabatic temperature rise. Thus

$$\theta_1 = T_p + T_o - (T_3 + T_2)$$

NOTE — Temperature loss T_1 is neglected in this calculation.

4.2.7.5 The total heat loss (q) is calculated by summation of q_3, q_2 and q_1. Thus

$$q = q_3 + q_2 + q_1$$

or temperature equivalent of the heat loss q is

$$T_L = \frac{q}{C\rho D} = T_3 + T_2 + T_1$$

4.2.8 *Evaluation of Thermal Stress*

Magnitude of thermal stress developed due to temperature change using the stress temperature relation may be computed from the following formula:

$$f = \alpha E_p R\,(T_p + T_o - T_L - T_s)$$

where

f = thermal stress resulting due to temperature gradient in MPa (This thermal stress should be limited to permissible tensile stress which is about 10 percent of the compressive strength),

α = coefficient of thermal expansion on concrete,

E_p = sustained modulus of elasticity of concrete in MPa. In absence of laboratory values it can be taken as approximately 0.5 to 0.6 times the instantaneous modulus of elasticity of concrete (lower values being applicable when concrete is loaded at early ages, that is 2 days, 7 days, etc, after casting and higher values applied when concrete is loaded at later ages, that is 90 days, 365 days etc. Intermediate values are applicable for intermediate loading ages).

R = restraint factor. It has value of 1 at the contact of dam and foundation and also at a level where concreting is interrupted for a period of more than two weeks time. It decreases rapidly at higher levels. It may be taken as

0.5 at a height of about 0.15 B, where B is the base width of the dam at foundation level or at the level where R has been taken as 1,

T_p = placement temperature of concrete in °C,

T_o = ultimate adiabatic rise in temperature of concrete in °C,

T_L = temperature loss, that is $T_1 + T_2 + T_3$ in °C, and

T_s = final stable temperature of dam in °C.

A typical example illustrating the computation for determination of thermal properties of mass concrete is given at Annex A.

5 METHODS OF TEMPERATURE CONTROL

5.1 Most commonly used methods are precooling, post cooling and reducing heat of hydration by proper mix design. The ideal condition would be simply to place the concrete at stable temperature of dam and heat of hydration removed, as it is generated, so that temperature of concrete is not allowed to rise above stable temperature. However this is not possible to achieve practically. Therefore, the most practical method is to precool concrete so as to restrain the net temperature rise to acceptable levels.

5.2 Precooling

5.2.1 One of the most effective and positive temperature control measure is precooling which reduces the placement temperature of concrete (*see* **4.2.6.2**). The method, or combination of methods, used to reduce concrete placement temperatures will vary with the degree of cooling required and the equipment available with the project authority or the contractor. In this method usually the fine and coarse aggregates and the water are separately cooled to the requisite temperatures.

5.2.1.1 Mixing water may be cooled to varying degrees, usually from 0°C to 4°C. Adding crushed ice or ice flakes to the mix is an effective method of cooling because it takes advantage of the latent heat of fusion of ice. The addition of large amount of ice flakes, however, may not be possible in cases where both coarse aggregate and sand contain appreciable amount of free water, in which case the amount of water to be added to the mix may be so small that substitution of part of the water to be added with ice may not be feasible. From practical considerations, not more than 70 percent of water should be replaced by crushed ice.

Although most rock minerals have comparatively low heat capacity, since aggregates comprise the greatest proportion of concrete mix, the temperature of the aggregate has the greatest influence on the temperature of the concrete. Cooling of coarse aggregate to about 1.7°C may be accomplished in several ways. One method is to chill the aggregates in large tanks of refrigerated water for a given period of time or by spraying cold water. Effective cooling of coarse aggregate is also attained by forcing refrigerated air through the aggregate while the aggregate is draining in stock piles, or while it is in a conveyer belt or while it is passing through the bins of the batching plant.

5.2.1.2 Sand may be cooled by passing it through vertical tubular heat exchangers. A chilled air blast directed on the sand as it is transported on conveyer belts may also be used. Sand may also be cooled by passing it through screw conveyers, the blades of which carry chilled water inside. Immersion of sand in cold water is not practical because of the difficulty in removing free water from the sand after cooling. This also leads to bulking of sand.

5.2.1.3 Cementitious materials used in concrete are hydraulic materials, so their quality control requires that they be handled and batched dry. If the temperature of the cement is brought down below the dew point of the surrounding atmosphere, moisture will condense and adversely affect the ultimate quality of the cement. Generally, the temperature of bulk cement supplied is about 37°C; hence it neither cools naturally nor looses a sizable portion of excess heat before it is used. Therefore, cooling of cement is not normally done.

5.2.1.4 *Refrigeration plant capacity*

As the temperatures of aggregates will generally follow the annual cycle of ambient air temperature, the refrigeration plant capacity requirement should be determined for a specific segment of time, that is for a week or a month. The refrigeration may be designed to produce a single material, such as ice, or may be divided into various cooling systems for production of ice, chilled water and/or cooled air according to heat balance needs. The size of the cooling plant required is expressed in tonnes of refrigeration. Refrigeration capacity of plant is worked out in terms of ice equivalent (*see* Annex B).

5.3 Post Cooling

5.3.1 Post cooling is a means of crack control. Control of concrete temperature may be effectively accomplished by circulating cold water through thin walled pipes embedded in concrete. This will reduce the temperature of newly placed concrete by several degrees, but the primary purpose of the system is to accelerate the subsequent heat removal and accompanying volume decrease, during early ages when the elastic modulus is relatively low. Post cooling is also used where longitudinal contraction joints are provided in order to reduce the temperature of concrete to the desired value prior to grouting of transverse contraction joint. Post cooling will create a flatter temperature gradient between the warm concrete and the cooler exterior atmosphere which, in turn, helps in avoiding temperature cracks. Other methods such as evaporative cooling with a fine water spray, cold water curing and shading may prove beneficial, but the results are variable and do not significantly affect the temperature in the interior of massive placement.

5.3.1.1 The embedded cooling system consist of aluminium or synthetic plastic pipe or tubing generally of 25 mm dia and 1.50 mm wall thickness placed in grid like coils over the top of each concrete lift. When the expected active cooling period exceeds 3 months, steel tubing should be used. The number of coils in a block depends upon the size of the block and the horizontal spacing of the pipes. For practical reasons, pipe coils are placed and tied to the top of a hardened concrete surface and thus vertical spacing of the pipe corresponds to lift thickness. A horizontal spacing same as the vertical spacing will result in the most uniform cooling pattern but variations may be allowed. Supply and return headers, with manifolds to permit individual connections to each coil are normally placed on the downstream face of the dam. In some case, cooling shafts, galleries and embedded header system may be used to advantage.

5.3.1.2 Postcooling by running chilled water through embedded pipes is nowadays recommended only when longitudinal joints are provided. Postcooling is generally avoided mainly because it is costlier than precooling system. Improved techniques for precooling the dry components would be beneficial when a large reduction in placement temperature is necessary. With recent advancement in concrete technology, the quantity of cement used for producing concrete of required strength has been reduced appreciably and thus postcooling may not be considered necessary in dams.

5.4 Pre-design Measures for Achieving Temperature Control

Cracking tendencies in concrete due to temperature changes may be reduced to an acceptable level by suitable design and construction procedures. The volumetric changes are caused by the temperature drop from the peak temperature attained by concrete shortly after placement to the final stable temperature of the structure. To bring down net temperature rise to acceptable limits, in order to avoid cracking, the parameters given in **5.4.1** to **5.4.4** are to be predetermined or suitably modified for a concrete dam.

5.4.1 The cement content in the concrete plays an important role in evolution of heat of hydration. By suitably modifying the concrete mix design, the quantity of cement per cubic metre of concrete may be reduced so as to reduce the amount of heat generated by cement.

5.4.2 The height of the placement lift is generally governed by economic considerations. Shallow lifts not only slow down the construction but also result in increased construction joints which entail additional costs for cleaning and preparation for placement of the next lift. The thickness of lift is also related to the temperature control measures proposed and the ambient temperature at the site. To reduce the net temperature rise, the lift thickness should be reduced if time is not a constraint.

5.4.3 There is always some time lag between placement of concrete in successive lifts. Depending upon ambient temperatures, these delays can be beneficial or harmful. Allowance of sufficient time between two construction lifts to allow large dissipation of heat from the surface is an effective and important factor to control the rise in the temperature during construction. The minimum elapsed time between placing of successive lifts in any block is usually restricted to 72 hours, but temperature studies should be made to relate heat loss or heat gain to the placement lift heights.

5.4.4 During summer months the ambient temperature is very high and, as such, heat gain from the atmosphere is also high. This may be reduced by continuous curing of the concrete by sprinklers using river water, after concrete has set. In such a case, ambient temperature for calculation purposes may be assumed as average of curing water temperature and actual ambient temperature.

ANNEX A

(*Clause* 4.2.8)

TYPICAL ILLUSTRATION FOR DETERMINATION OF THERMAL PROPERTIES OF MASS CONCRETE IN HEATING ZONE OF A CONCRETE DAM

Data

1	Mix proportion of concrete by mass (Cement:Fine aggregate: Coarse aggregate)	:	1 : 2.56 : 11.54
2	Cement content of concrete	:	162 kg/m^3
3	Total coarse aggregate in concrete	:	1 928 kg/m^3
4	Total fine aggregate in concrete	:	416 kg/m^3
5	Total water content in concrete	:	89 kg/m^3
6	Density of concrete (ρ)	:	2 610 kg/m^3
7	Mean annual air temperature	:	27.8°C
8	Mean summer temperature	:	31.7°C
9	Mean winter temperature (November to February)	:	24.4°C
10	Mean annual river water temperature	:	26.7°C
11	Specific heat of concrete (C)	:	857.33 J/kg°C
12	Thermal conductivity of concrete (K)	:	2.235 5 J/m.s.°C
13	Ultimate adiabatic rise in temperature (T_0)	:	21.8°C
14	Factor *m* for the concrete	:	0.025 per h
15	Exposure period of the lift (t)	:	72 h
16	Lift height (D)	:	1.50 m
17	Desired placement temperature of concrete	:	15.5°C
18	Temperature of ingredients of concrete at the time of mixing		
	a) cement	:	37.8°C
	b) coarse aggregate	:	21.1°C
	c) fine aggregate	:	32.2°C
	d) batched mixing water	:	26.7°C
19	Ice percent of mixing water	:	70 percent
20	Permissible temperature drop	:	11 to 16.7°C
21	Permissible tensile stress at 10 percent of the compressive strength of concrete	:	1.5 to 2.0 MPa
22	Co-efficient of thermal expansion of concrete (α)	:	4 × 10^{-6} per °C
23	Sustained modulus of elasticity of concrete ($E\rho$)	:	2 × 10^4 MPa
24	Restraint factor (R)	:	1.00

COMPUTATIONS

A) **Verification of Desired Placement Temperature of Concrete**

Placement temperature of concrete is computed by the formula given in **4.2.6.2**.

$$T_p = \frac{0.22\,(T_{ca}\,W_{ca} + T_{fa}\,W_{fa} + T_c\,W_c) + T_f\,W_f + T_w\,W_w - 79.6W_i}{0.22\,(W_{ca} + W_{fa} + W_c) + W_f + W_w + W_i}$$

$$T_p = \frac{0.22\,(21.1 \times 1\,928 + 32.2 \times 416 + 37.8 \times 162) + 32.2 \times 0 + 26.7 \times 89 \times 0.3 - 70.6 \times 89 \times 0.7}{0.22\,(1\,928 + 416 + 162) + 0 + 89 \times 0.3 + 89 \times 0.7}$$

$$T_p = \frac{0.22\,(40\,680.8 + 13\,395.2 + 6\,123.6) + 0 + 712.89 - 4\,959.08}{0.22\,(2\,506) + 89}$$

$$T_p = \frac{13\,243.91 - 4\,246.19}{551.32 + 89} = \frac{8997.72}{640.32} = 14.05°\mathrm{C}$$

The placement temperature at the site of work is expected to be about 15.5°C as desired.

B) **Determination of Loss of Heat from the Surface of the Lift**

i) The drop in temperature of the concrete due to heat loss q_3 is obtained by the following formula:

$$T_3 = \eta \ T_o$$

The value of η is obtained from Fig. 1 after calculating mt and $D/\sqrt{4h_d^2 t}$

m = 0.025 per hour and t = 72 h

mt = 0.025 × 72 = 1.80

and $$\frac{D}{\sqrt{4h_d^2 t}} = \frac{1.50}{\sqrt{4 \times h_d^2 \times 72}}$$

The diffusivity h_d^2 of concrete is calculated by the formula:

$$h_d^2 = \frac{K}{C\rho} = \frac{2.235\ 5}{857.33 \times 2\ 610}$$

$$h_d^2 = 9.994 \times 10^{-7} \text{ m}^2\text{/s}$$

or $$h_d^2 = 3.598 \times 10^{-3} \text{ m}^2\text{/h.}$$

Hence $$\frac{D}{\sqrt{4 h_d^2 t}} = \frac{1.50}{\sqrt{4 \times 3.598 \times 10^{-3} \times 72}} = 1.473\ 5$$

Now, corresponding to the values of mt = 1.8 and $D/\sqrt{4h_d^2 t}$ = 1.47 the value of η as obtained from Fig. 1 is 0.25.

Thus, T_3 = 0.25 T_o

= 0.25 × 21.8

= 5.45 °C

NOTE — In the absence of laboratory data, the value of T_o may be calculated by the formula given in **4.2.6.1** as illustrated below:

Assuming heat of hydration of cement, H = 343 527 J/kg

Effective cement content (W) considering 25 percent pozzolana content of efficiency 0.50

= 162.00 × 0.75 + 162 × 0.25 × 0.50 = 141.75 kg/m³

$$\text{Thus, } T_o = \frac{HW}{\rho C} = \frac{343\ 527 \times 141.75}{2\ 610 \times 857.33}$$

= 21.76°C say 21.8°C

ii) The temperature drop due to heat loss q_2 is calculated by the formula:

$$T_2 = \frac{2h_d^2 \theta_o}{D\sqrt{\pi}} \left[\sqrt{\frac{t}{h_d^2}} - I \right]$$

Now θ_0 = Placement temperature — Atmospheric temperature

$= 15.5 - 31.67$

$= -16.2°C$

$h_d^2 = 3.598 \times 10^{-3}$ m²/hr.

$D = 1.5$ m

$t = 72$ h.

$$\text{Hence } \frac{D}{\sqrt{4h_d^2 t}} = \frac{1.50}{\sqrt{4 \times 3.598 \times 10^{-3} \times 72}} = 1.473\ 5$$

$$\text{From Fig. 2, } \frac{I}{D/2h_d^2} = 0.011$$

$$\text{Hence, } I = \frac{0.011 \times 1.5}{2 \times (3.598 \times 10^{-3})} = 2.30$$

$$T_2 = \frac{2\times\left[3\cdot598\times10^{-3}(-16\cdot2)\right]}{1\cdot5\times\sqrt{\pi}} \times \left[\sqrt{\frac{72}{3\cdot598\times10^{-3}}} - 2\cdot3\right] = -0.043\ 8\ (139.16)$$

$= -6.09°C$

iii) Temperature drop due to heat loss q_1 is calculated by the formula:

$$T_1 = \frac{2h_d^2\theta_2}{D\sqrt{\pi}} \times I$$

Here $\theta_2 = (T_p + T_o - T_3 - T_2)$ – atmospheric temperature

$= (15.5 + 21.8 - 5.45 + 6.09) - 31.7$

$= 6.2°C$

$$\text{Hence } T_1 = \frac{2 \times (3.598 \times 10^{-3}) \times 6.24 \times 2.30}{1.5\sqrt{\pi}}$$

$= 0.04°C$

Therefore, the total temperature drop due to loss of heat from the exposed surface of the lift,

$T_L = T_3 + T_2 + T_1$

$= 5.45 - 6.09 + 0.04$

$= -0.6$

C) **Evaluation of thermal stresses**

Maximum temperature attained by concrete

$= T_p + T_o$ – losses

$= 15.5 + 21.8 - (-0.6)$

$= 37.90°C$

Final stable temperature of concrete, T_s is equal to mean annual air temperature.

Thus $T_s = 27.8°C$

Thermal stresses, $F = \alpha\ E_p\ R\ (T_p + T_o - T_L - T_s)$

$= 4 \times 10^{-6} \times 2 \times 10^4 \times 1\ (15.5 + 21.8 + 0.6 - 27.8)$

$= 0.81$ MPa < 1.5 MPa, hence acceptable.

ANNEX B

(*Clause* 5.2.1.4)

DETERMINATION OF REFRIGERATION PLANT CAPACITY

B-1 The capacity of refrigeration plant can be designed so as to constitute all cooling media into one material such as production of ice or can be divided into different cooling systems such as production of ice, chilled water and/or chilled air according to requirements of heat balance. Use of ice is one of the basic methods to lower the concrete placement temperature. Refrigeration capacity of plant is worked out in terms of ice equivalent.

B-2 EXAMPLE

It is proposed to cool coarse aggregate (CA) having temperature of 32.22°C to 26.67°C using river water at a temperature of 26.67°C, then further cooling to 21.11°C by chilled water having temperature of 0°C.

Following data has been used for estimating the refrigeration capacity of the plant:

Specific heat of coarse aggregate	= 946.216 8 J/kg°C
Specific heat of water	= 4 186.8 J/kg°C
Heat of fusion of ice	= 334 609 J/kg°C

Heat required to be extracted from CA to lower the temperature from 26.67°C to 21.11°C.

= Wt of CA × Sp heat of CA × Temperature difference
= 1 928 × 946.216 8 × (26.67°C − 21.11°C)
= 10 143 141 J/m^3.

Heat available from every kilogram of chilled water at 0°C to lower the temperature of CA to 21.11°C.

= Sp heat of water × temperature difference
= 4 186.8 × (21.11°C − 0°C)
= 88 383.348 J/kg.

Therefore, quantity of chilled water at 0°C required for cooling the coarse aggregate up to 21.11°C.

$$= \frac{10\ 143\ 141}{88\ 383.348}$$

= 114.76 kg/m^3

Since it would be necessary to immerse the aggregates in chilled water completely, it is assumed that 20 percent extra quantity would be necessary for cooling coarse aggregate up to 21.11°C.

Quantity of chilled water at 0°C required per cubic metre of concrete:

= 1.20 × 114.76
= 137.71 kg

Heat required to be extracted from river water at 26.67°C to chill it to 0°C, per cubic metre of concrete:

= Weight of chilled water × sp heat of water × temperature difference

= 137.71 × 4 186.8 × (26.67°C − 0°C)

= 15 376 968 J

Equivalent chilled water quantity per cubic metre of concrete

$$= \frac{15\ 376\ 968}{334\ 609 + (4\ 186.8 \times 21.11)}$$

= 36.35 kg

Now considering a batching plant capacity of 800 cubic metre of concrete per day,

Ice equivalent of chilled water quantity needed per day

$$= 800 \times 36.35 = 29\ 080 \text{ kg}$$

The ice required in place of water is proposed to be about 70 percent; therefore, quantity of ice required for mixing per cubic metre of concrete:

$$= 89.00 \times 0.70$$

$$= 62.30 \text{ kg}$$

Assuming 25 percent wastage, total quantity of ice required per cubic metre of concrete

$$= 62.30 \times 1.25$$

$$= 77.875 \text{ kg}$$

Again considering a batching plant capacity of 800 cubic metre of concrete per day.

Ice required per day = $800 \times 77.875 = 62\ 300$ kg

Total ice required is

$$= 29\ 080 + 62\ 300$$
$$= 91\ 380 \text{ kg}$$

Total kilo Joule equivalent of 91 380 kg of ice per day

$$= 91\ 380\ [334.609 + 4.186\ 8 \times (26.67)]$$

$$= 40\ 780\ 244 \text{ kJ/day}$$

The refrigeration capacity of a plant in terms of Tonne Refrigeration (TR), assuming that 1 TR is equivalent to 3.489 kJ/s and the plant works for 16 hours a day, is given by:

$$\text{TR} = \frac{40\ 780\ 244}{3.89 \times 3\ 600 \times 16}$$

$$= 202.9 \text{ TR}, \quad \text{say } 203 \text{ TR}$$

Assuming 35 T R for cooling of the building and surroundings, total capacity of refrigeration plant

$$= 35 + 203$$

$$= 238 \text{ TR.}$$

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