STUDIES ON MASS CONCRETE DESIGN MIX TOWARDS TEMPERATURE CONTROL IN GRAVITY DAM – A CASE STUDY

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ABSTRACT

During construction of gravity dams in mass concrete, rise in the temperature of concrete due to heat of hydration of cement may develop thermal gradient between internal temperature of concrete and surrounding air temperature causing development of tensile stresses in dam body which may result cracking if the induced stresses are more than the tensile strength of concrete at early stages. Hence, careful determination of thermal properties and estimation of suitable placement temperature becomes essential to avoid cracking. These studies include evaluation of strength properties, thermal properties i.e. adiabatic temperature rise, thermal diffusivity, coefficient of thermal expansion, creep parameters and elastic properties such as modulus of elasticity and Poisson's ratio of mass concrete. This paper discusses a case study of temperature control in Polavaram dam. Polavaram composite dam being constructed across Godavari River in West Godavari district of Andhra Pradesh consists of two earthen portions and mid concrete gravity spillway. The spillway is being constructed using mass concrete design mix consisting of M15 and M20 grade equivalent mixes. The major inner portion of the spillway is being constructed using M15A80 grade equivalent mass concrete design mix having maximum size of aggregate (MSA) as 80 mm. The studies involved estimation of strength parameters, thermal properties and analysis of measured parameters to arrive at suitable placement temperature and lift height by maintaining lift interval of 72 hrs under average annual air and mean summer temperatures. Pre-cooling requirements have been estimated to maintain requisite placing temperature during different climatic conditions. Based on the extensive laboratory studies and site conditions, it has been recommended that construction of spillway in mass concrete needs to be carried out by maintaining placement temperature at 13°C and lift height of 1.5 m at lift interval of 72 hours between two successive lifts during annual mean air temperature at 28.9°C. Similarly, during mean summer air temperature at 31.5°C, the placement temperature of mass concrete needs to be maintained at 12°C by maintaining a lift height of 1.5 m and lift interval of 72 hours between two successive lifts. Continuous curing of placed concrete lifts with water, using suitable arrangement has been recommended to maintain maximum temperature rise within allowable limits. Spillway of Polavaram dam is being constructed by following the temperature control recommendations given by CWPRS.

1. INTRODUCTION

Concrete gravity dams are constructed in mass concrete involving placement of huge quantity of concrete in a stipulated time interval. In mass concrete dams, during construction, rise in the temperature of concrete due to heat of hydration of cement, may develop thermal gradient between inner temperature of concrete and surrounding air temperature. These thermal gradients result in development of tensile stresses in dam body which may cause initiation of cracks if the induced stresses are more than the tensile strength of concrete at early stages. Hence, careful determination of thermal properties and estimation of suitable placement temperature becomes essential to avoid cracking. These studies include evaluation of strength properties, thermal properties i.e. adiabatic temperature rise, thermal diffusivity, coefficient of thermal expansion, creep parameters and elastic properties such as Modulus of Elasticity and Poisson's ratio of mass and roller compacted concrete. The laboratory studies carried out at CWPRS for Polavaram concrete gravity spillway has been discussed in this paper. Polavaram, a composite dam (Fig.1) being constructed across Godavari River in West Godavari district of Andhra Pradesh consists of two earthen portions and mid concrete gravity spillway. The spillway is being constructed using mass concrete design mix consisting of M15 and M20 grade equivalent mixes. The major inner portion of the spillway is being constructed using M15A80 grade equivalent mass concrete design mix having maximum size of aggregate (MSA) as 80 mm. The studies involved estimation of strength parameters, thermal properties and analysis of measured parameters to arrive at suitable placement temperature and lift height by maintaining lift interval of 72 hrs under average annual air and mean summer temperatures. Pre-cooling requirements have been estimated to maintain requisite placing temperature during different climatic conditions.

Fig. 1 : View of Polavaram Dam

2. THE CONCRETE MIX PROPORTIONS

The Details Of Concrete Mix Proportion Obtained From Polavaram Project Site Based On Mix Design Carried Out For Mass Concrete In Spillway Blocks, Are Given In Table 1

Table 1 : Concrete Mix Proportions

Mix Type	Cement content (kg/m^3)	Coarse Aggregate (kg/m^3)				Sand (kg/m^3)	Water (kg/m^3)	Admixture (kg/m^3)
	Cement (PPC Nagarjuna)	80-40 mm	40-20 mm	20-10 mm	10-5 mm	River Sand		MYK Schomb-urg – SP 111
M15A80	210.0	626	428	330	263	614	126	3.57

3. PROCEDURE FOR TEMPERATURE CONTROL STUDIES

The actual placement temperature to obtain crack free concrete can only be ascertained after determining the strength, thermal and elastic properties of mass concrete and estimating placement temperature by carrying out relevant computations for evaluation of thermal stress. The placement temperature has been estimated by taking into consideration site climatological data, data obtained through laboratory studies and other parameters. The cooling requirements of concrete before pouring, have been worked out based on average site climatological data and placement temperature. Mass concreting in progress at dam base in spillway blocks as shown in the Fig. 2.

Fig. 2 : Mass concreting in progress at Polavaram Dam

The problem of temperature control in mass concrete gravity spillway of Polavaram dam has been carried out by determining the strength, elastic and thermal properties as detailed below.

3.1 Determination of strength and elastic properties of mass concrete

3.1.1 *Compressive Strength*

The average compressive strengths under wet screening and original mix design have been carried out in laboratory and are as given in Table-2. From the results, it has been observed that, the compressive strength of the wet screen concrete is less as compared to actual design mix concrete. Moreover strength obtained from cylindrical specimens is slightly lower than the cubical specimens. The compressive strength of the design mix after 3,7,28 and 90 days satisfy the design mix requirements proposed by Project Authorities.

Table 2 : Average Compressive strength properties of the concrete mix

Age	**3 days**	**7 days**	**28 days**	**90 days**
Wet Screened mix through 40 mm IS sieve				
Cylinder Compressive Strength	52.72 kg/cm^2	88.65 kg/cm^2	235 kg/cm^2	-
Full mix (Unscreened mix)				
Cube Compressive strength	92.59 kg/cm^2	114.8 kg/cm^2	>200 kg/cm^2	-
Cylindrical compressive strength of **core obtained from cube**	-	98 kg/cm^2	235 kg/cm^2	278 kg/cm^2

3.1.2 *Modulus of Elasticity*

The average computed value of Modulus of Elasticity after 3,7,28 and 90 days period has been given in Table 3. It has been observed that, the Modulus of Elasticity of mass concrete after 28 days is comparable with theoretical value as per BIS.

Table 3 : Average Young's Modulus of Elasticity properties of the concrete mix

Age	3 days	7 days	28 days	90 days
Young's Modulus of Elasticity *(Based on laboratory test on 300 mm cube using design mix of M15A80)*	**1.5 x 10^5** (kg/cm^2)	**1.67 x 10^5** (kg/cm^2)	**2.0 x 10^5** (kg/cm^2)	**2.9 x 10^5** (kg/cm^2)
(Based on laboratory test on extracted cylinders of size 150 mm dia X 300 mm high)	-	**1.7 x 10^5** kg/cm^2	**2.2 x 10^5** kg/cm^2	**2.95 x 10^5** kg/cm^2

3.1.3 *Split Tensile Strength of Cylindrical Specimen*

The average split tensile strength after 3, 7, 28 and 90 days period are given in Table 4.

Table 4 : Average Split Tensile Strength of extracted cylindrical specimens

Age	**3 days**	**7 days**	**28 days**	**90 days**
Split Tensile Strength *(Based on laboratory test on cylinders of size 150 mm dia. x 300 mm height casted using wet screened mix through 40 mm IS sieve)*	**10.85** kg/cm^2	**16.27** kg/cm^2	**-**	**-**
Split Tensile Strength *(Based on laboratory test on extracted cylinders of size 150 mm dia. x 300 mm high)*	**-**	**-**	**16.80** kg/cm^2	**23.06** kg/cm^2

3.2 Determination of Thermal Properties of Mass Concrete

The thermal properties namely adiabatic temperature rises, thermal diffusivity, coefficient of thermal expansion, have been determined experimentally in the laboratory as per the procedure laid down in the relevant USBR standards. Various laboratory tests such as measurement of adiabatic temperature rise, thermal diffusivity and coefficient of linear thermal expansion, have been determined by testing casted samples of various shapes and sizes using the suggested mix design and supplied ingredients. Based on the results of the laboratory tests, thermal stresses have been computed and placement temperature, lift height and lift intervals have been evaluated and are mentioned in brief as below:

3.2.1 *Estimation of Adiabatic Temperature Rise*

For measurement of ultimate temperature rise (to be used for computation of adiabatic temperature rise) nearly 0.0283 cubic meter (one cubic feet) of freshly mixed design mix concrete sample sealed in a polythene bag, has been kept in a plastic container and sealed in an properly insulating wooden box known as adiabatic calorimeter, to arrest escape of the moisture as well as transfer of heat for simulating adiabatic conditions as shown in Fig. 4. The temperature of the concrete mix and the chamber are measured by highly sensitive platinum resistance temperature detector (PRTD). To achieve the adiabatic condition, the temperature of the chamber is so adjusted that difference between the specimen temperature and chamber temperature at any time does not exceed 0.5° C.

Fig. 4 : Test set up for measuring adiabatic temperature rise

Under adiabatic conditions, the temperature rise in the concrete mix sample has been monitored and recorded for a period of 7 days during which 90% of heat is generated. The rise in temperature of concrete is plotted against time in hours as shown in Fig. 5.

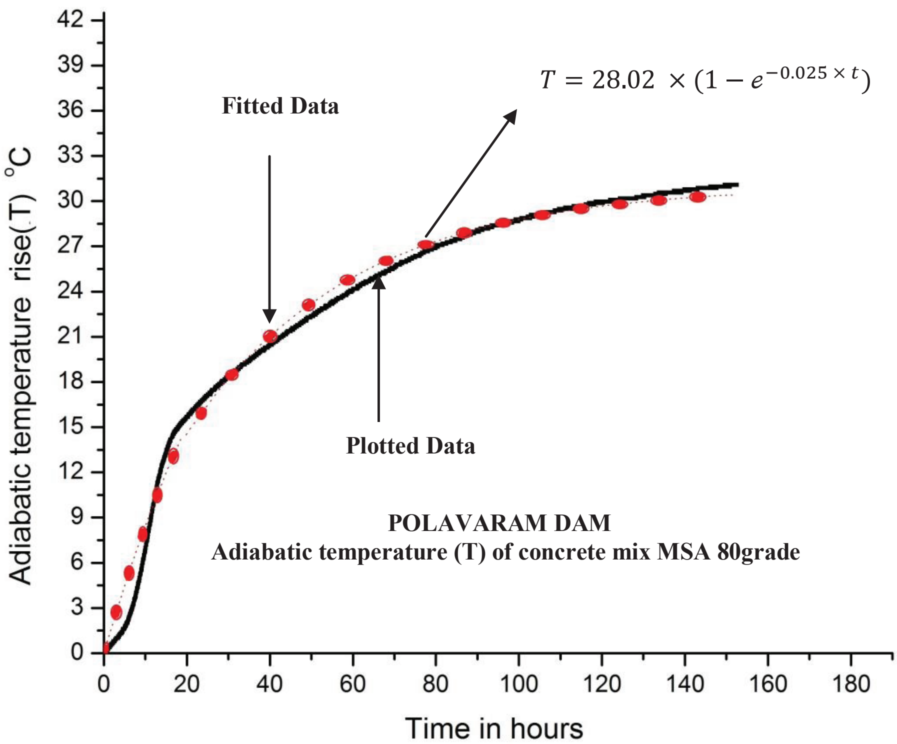

Fig. 5 : Adiabatic temperature rise Vs Duration

Following adiabatic temperature rise equation (Eq. 1) has been obtained based on plotted and fitted measured adiabatic temperature data:

$$T = 28.02 \times (1-e^{-0.025 \times t}) \qquad ...(1)$$

Therefore, constants obtained from above equation are:

$T_o = 28.02°$ C

m = 0.025 per hour respectively.

3.2.2 *Thermal Diffusivity (h^2)*

Diffusivity is an index of the facility with which concrete diffuses heat in all direction. The equipment consists of hot water bath, in which water is heated through immersed heater. Cured concrete specimen is placed in the water bath at room temperature. The thermometer is inserted in the hole provided and then sealed properly. The water in the bath is then heated to a certain temperature so that concrete sample is heated up sufficiently without cracking. The specimen is then allowed to saturate in the hot water. After achieving saturation, hot water is flushed out and cold water is let in. The diffusivity test set up is as shown in Fig. 6. The temperature in the interior of specimen is recorded at every 5 minutes interval upto a period of 1 hour. From this data, cooling history of the concrete specimen is obtained. The measured temperature data is used to compute the value of θ/θ_o. Knowing the value of θ/θ_o the value of h^2t/D^2 has been obtained from the standard plot between h^2t/D^2 and θ/θ_o as shown in Fig.7. The diffusivity (h^2) is calculated from the values of t (which is 1 hour) and diameter of the specimen (D) as per USBR recommendations. Initially temperature difference remaining (θ/θ_o) is computed as follows (Eq. 2):

$$\frac{\theta}{\theta_0} = \frac{Stable\ temperature\ after\ cooling - temperature\ of\ cooling\ water}{Peak\ temperature\ after\ heating - temperature\ of\ cooling\ water} \quad (2)$$

Fig. 6 : Diffusivity Test set up

Based on measured temperature, part of original temperature difference remaining the value of diffusivity is determined from Fig. 7 as follows:-

$$\frac{\theta}{\theta_0} = \frac{33.7 - 28.4}{45.5 - 28.4} = \frac{5.3}{17.1} = 0.3099$$

$$h^2 = 0.071 \times 0.203 \times 0.203 \text{ (for t = 1 hr)}$$
$$h^2 = 0.002926\ m^2/hr$$

Average Diffusivity (h^2) value for the concrete mix found to be 0.0029 m^2/hour.

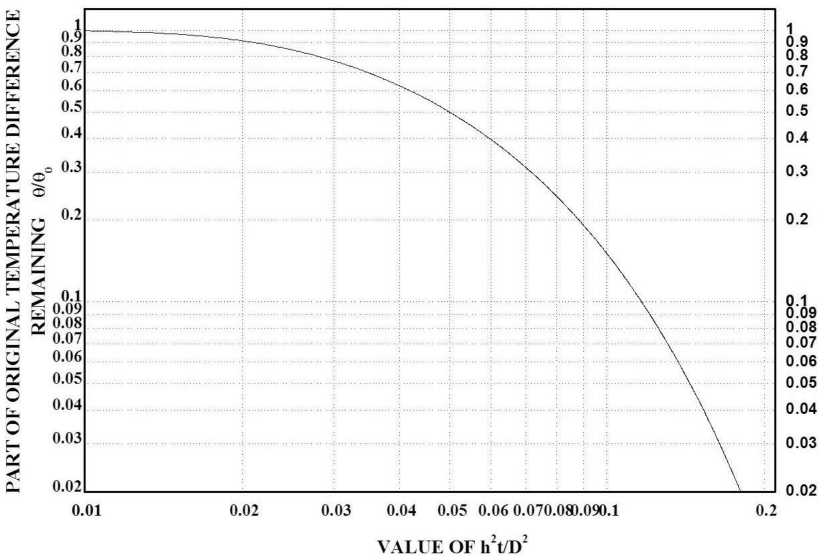

Fig. 7 : Standard plot of temperature change at centre of cylinder

3.2.3 Measurement of Linear Expansion

The linear expansion of the concrete sample, has been measured using embedded strain gauges. Concrete cylinder of 150 mm diameter x 300 mm long was casted and embedment type strain gauge was embedded in concrete during casting of the sample. After curing for seven days, the specimen is kept for heating in the water bath and initial reading of strain gauge is recorded. The specimen is heated continuously upto 60° C and strain gauge readings are recorded at different temperatures as shown in Fig. 8. The measured strain is plotted versus measured temperature and the coefficient of thermal expansion (α), has been computed as follows (Eq. 3):

$$\alpha = R_h - R_c / G\Delta T = \Delta\varepsilon / \Delta T \quad ...(3)$$

Where R_h = Length reading at higher temperature

R_c = Length reading at lower temperature

G = Gauge length

ΔT = Temperature rise of specimen

$\Delta\varepsilon$ = Strain rise due to increase in temperature

α = Coefficient of thermal expansion expressed as mm/mm/degree centigrade.

The average preliminary value of coefficient of thermal expansion of the concrete mix under study has been computed as 9×10^{-6} mm/mm/°C.

Fig. 8 : Test set up for measurement of Linear Expansion of concrete sample

4. COMPUTATIONS OF THERMAL STRESSES, ESTIMATION OF PLACEMENT TEMPERATURE, LIFT HEIGHT AND LIFT INTERVAL

4.1 Climatological Data

The concrete mass is expected to cool down and attain stability to maintain equilibrium with the average annual air temperature of the site. The process of cooling of concrete mass depends upon temperature rise in concrete with time, diffusion of heat and prevalent surrounding temperature at the dam site.

4.2 Maximum Temperature Rise inside the Dam (T_{max})

The estimation of maximum temperature (T_{MAX}), the interior of the concrete mass is computed by the following relation (Eq. 5),

$$T_{Max} = T_P + T_O + T_L \quad ...(5)$$

Where, T_P = Placement Temperature (to be estimated),

T_o = Ultimate Adiabatic Temperature rise

T_L = Temperature loss or gain due to diffusion/absorption of heat to/from the surroundings.

4.3 Evaluation of Thermal Stresses

Magnitude of thermal stresses developed due to temperature change using the stress temperature relation can be computed from the following Eq.(6).

$$f = \alpha . E_p . R . (T_p + T_0 - T_L - T_s) \quad ...(6)$$

where

- f = Thermal stress resulting due to temperature gradient (kg/cm^2)
- α = Coefficient of thermal expansion of concrete.
- E_p = Sustained modulus of elasticity of concrete (kg/cm^2)
- R = Restraint factor.
- T_P = Placement temperature of concrete in °C.
- T_0 = Ultimate adiabatic rise in temperature of concrete in °C.
- T_L = Temperature loss i.e. $T_1 + T_2 + T_3$ in °C.
- T_S = Final stable temperature of dam in °C.

The permissible thermal stress for the mix M15A80 under study has been computed to be 10.5 kg/cm^2 based on 72 hrs split tensile strength of concrete. The computation of thermal stresses for various combinations of lift heights ranging from 0.75 m to 2.0 m, lift interval of 72 hours is given in table 5 below by taking into account all available parameters. For constant lift interval of 72 hrs, placement temperature for different lift heights ranging from 0.75 m to 2.0 m has been estimated. The variation of placing temperature with different lift height is shown in Fig.9 for mean summer air temperature and average annual air temperature at Polavaram Project site.

It has been recommended to Project that (Fig. 5) for annual air temperature of 28.9° C, the mass concrete can be placed at a lift height of 1.5m maintaining a lift interval of 72 hours by maintaining placing temperature at 13° C. Similarly for mean summer air temperature of 31.5° C, the mass concrete can be placed at a lift height of 1.5m maintaining a lift interval of 72 hours by maintaining placing temperature at 12° C.

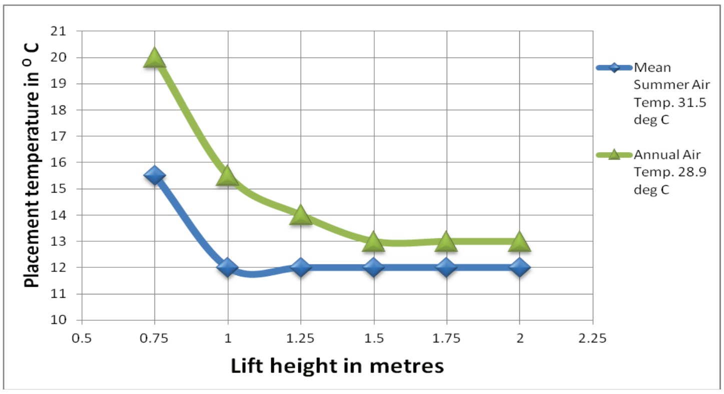

Fig. 9 : Placement temperature of mass concrete for lift interval of 72 hrs

Table 5 : Thermal stresses for various Lift heights

Lift Height	Lift Interval	Placement temp. T_P	Air temp. T_{air}	Temp Loss T_1	Temp Loss T_2	Temp Loss T_3	Max temp.. T_M	Total Temp Loss T_L	Adiabatic temp. rise T_O	Thermal Stress
m	Hrs	⁰ C	⁰ C	⁰ C	⁰ C	⁰ C	⁰ C	⁰ C	⁰ C	Kg/cm^2
0.75	72.00	15.50	31.51	1.11	-9.42	11.39	40.42	3.08	28.00	10.5
0.75	72.00	19.50	29.24	1.40	-5.73	11.39	40.44	7.06	28.00	10.5
0.75	72.00	20.00	28.89	1.43	-5.23	11.39	40.41	7.60	28.00	10.4
1.00	72.00	12.00	31.51	0.33	-9.51	9.14	40.05	-0.05	28.00	10.1
1.00	72.00	15.00	29.24	0.42	-6.94	9.14	40.38	2.62	28.00	10.4
1.00	72.00	15.50	28.89	0.44	-6.53	9.14	40.45	3.05	28.00	10.5
1.25	72.00	12.00	31.51	0.10	-7.96	7.51	40.35	-0.35	28.00	10.4
1.25	72.00	13.00	29.24	0.13	-6.62	7.51	39.99	1.01	28.00	10.1
1.25	72.00	14.00	28.89	0.14	-6.07	7.51	40.43	1.57	28.00	10.5
1.50	72.00	12.00	31.51	0.03	-6.75	6.31	40.41	-0.41	28.00	10.4
1.50	72.00	13.00	28.89	0.04	-5.50	6.31	40.15	0.85*	28.00	10.2
1.50	72.00	13.00	29.24	0.04	-5.62	6.31	40.27	0.73	28.00	10.3
1.75	72.00	12.00	31.51	0.01	-5.83	5.43	40.39	-0.39	28.00	10.4
1.75	72.00	13.00	28.89	0.01	-4.75	5.43	40.31	0.69	28.00	10.4
1.75	72.00	13.00	29.24	0.01	-4.85	5.43	40.41	0.59	28.00	10.5
2.00	72.00	12.00	29.24	0.00	-4.52	4.75	39.76	0.24	28.00	9.90
2.00	72.00	12.00	31.51	0.00	-5.11	4.75	40.36	-0.36	28.00	10.4
2.00	72.00	13.00	28.89	0.00	-4.16	4.75	40.41	0.59	28.00	10.4

*Computed value of total temperature loss as shown above in sample calculation.

5. CONCLUSIONS

Based on the studies discussed in this paper following conclusions are drawn:

1. Temperature control studies prior to construction of the dam, is a very important aspect to avoid thermal cracking and finalize construction schedule including pre and post cooling requirements.
2. Based on the extensive laboratory studies for Polavaram Project, it has been recommended that for annual air temperature of 28.9° C**,** the mass concrete temperature during placement should be maintained at 13° C by limiting maximum lift height of 1.5 m and lift interval of 72 hours between two successive lifts.
3. Similarly for mean summer air temperature of 31.5° C the mass concrete can be maintained at 12° C placement temperature by maintaining a lift height of 1.5 m and lift interval of 72 hours between two successive lifts.
4. The coarse aggregate has been suggested to be kept cooled during summer season.
5. By following the recommendations of CWPRS, the spillway Polavaram project is being constructed in mass concrete without development of any thermal cracks.

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