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Thermo-structural monitoring of RCC dam in India through instrumentation

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Abstract. The knowledge of the behavior of any roller compacted concrete (RCC) dam and its foundation is gained by studying the service action of the dam and its foundation using measurements of an external and internal nature. The information by which a continuing assurance of structural safety of the RCC dam can be gauged is of primary importance. Similarly, the fact that the information on structural and thermal behavior and the properties of concrete that may be used to give added criteria for use in the design of future RCC dams is of secondary importance. Wide spread attention is now being given to the installation of more expensive instrumentation for studying the behavior of concrete dams and reservoirs and forecasting of any adverse trends. In view of this, the paper traces installation and need of the comprehensive instrumentation scheme implemented to monitor the structural and thermal behavior of 102.4 m high RCC dam constructed near Mumbai in India. An attempt is made in the present paper to emphasize the need to undertake an instrumentation program and evaluate their performance during construction and post construction stage of RCC structures. Few typical results, regarding the thermal and structural behavior of the dam, obtained through instrumentation installed at the dam site are presented and compared with the design considerations. The fair agreement is seen in the response observed through instrumentation with that governing the design criteria.

Keywords: roller compacted concrete (RCC); instrumentation; thermocouples; thermal stresses; mass concrete structure (MCS)

1. Introduction

The 102.40 m high middle Vaitarna dam (MVD) mainly consists of a left non -overflow section from the record distance (RD) 15 m to 76 m, over-flow section from RD 76 m to 172 m with PMF capacity of 6800 cumecs, and right non- overflow section from RD 172 m to 565 m. The maximum ambient temperature at site ranges from 44° Celsius to a minimum of 7° Celsius. The total length of the dam is 565 m with its riverbed level at 187.78 m and top level at 287.70 m. The overflow section is 96 m long with 5 bays of 15 m wide and 6 piers of 3.5 m width. The overflow section is ogee shaped and designed as high ogee. The overflow section (Fig. 1) consists of 5 radial gates of 15 m × 12 m size and a trajectory bucket type energy dissipation arrangement with sloping apron.

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The dam mainly comprises of roller compacted concrete (RCC), which is placed layers, with each layer being 30 m thick. Both the faces are made up of grout enriched vibrated (GEVR) RCC. The piers, crest and glacis for the overflow section has been constructed with the conventional concrete (CVC). Total length of the non-overflow section is 454 m in which left non-overflow section is 61 m and constructed with the conventional concrete.

The right non-overflow section is 393 m long and constructed with roller compacted concrete. The spillway portion of length 96 m is constructed with the RCC up to the bottom level of piers, i.e., up to a level of 253 m. With the maximum rate of RCC placement rate (1.2 lacs cubic metre per month), the MVD has become the tenth fastest RCC Dam in the World. The total RCC volume placed is 12.30 lacs cubic metre within the period of 15.2 months.

The Vaitarna river, a west - flowing river originating from Sahyadri ranges, in the state of Maharashtra of India is one of the major sources of the water supply to the city of Mumbai. After the construction of the middle Vaitarna dam, the releases from upper Vaitarna power station would flow in to the middle Vaitarna reservoir. The city's present population is 14.50 million which is expected to be 21.21 million as per forecast. The supply of water is one of the major factors, which leads to development of city. The present supply of water to Mumbai is drawn from existing four major and two minor sources. With the completion of this proud endeavour, the municipal corporation of greater Mumbai (MCGM) will be in a position to the meet the demand of water of the city.

2. Necessity of dam instrumentation

The RCC dams are built to last many decades and forms a key structure to the development of river basin potential for intended purpose. The consideration of the disastrous effect of the failure of dam in terms of loss of life and property make it imperative that the means are available in the dam providing information on assurance of its safety and serviceability. The instruments embedded in or installed at dam surface keep a constant watch over their performance in service and indicate distress spots in addition. The study of structural behavior of the dam provides an important aid in modifying the purely theoretical treatment so as to include the effect of actual field conditions. Moreover, the information obtained from the measurement helps in understanding of the influence of various parameters on the structural behaviour and leads to the formulation of more realistic design criteria.

Fig. 1 Downstream view of completed 102.4m tall Middle Vaitarna RCC Dam

Though only a small percentage of dams develop problems, it is impossible to predict those that would develop problems because of highly indeterminate nature of the structures and infinite number of possible variations in conditions that could affect the safety of RCC dam or appurtenant structures. Therefore, it is prudent that any dam which may affect the public safety has basic instrumentation to monitor vital signs**.** The dam is expected to safely withstand the forces created by impoundment of water over a long period. Proper and safe functioning of a dam is an extremely important matter of economic benefits and public safety. This makes it essential to gather information on the performance of the behavior of the dam during (i) construction, (ii) first filling of reservoir and lastly, (iii) during long-term service operation. The instruments are the tools that can monitor the integrity of hydraulic structures during the afore-mentioned three stages.

3. Brief review of literature

The literature pertaining to the instrumentation, theoretical and numerical analysis for predicting the structural and thermal behavior of roller compacted concrete (RCC) dams is reviewed briefly. Curtis (1967) discussed about the instrumentation in Scottish Dams. Jones (1968) reported the computations of the strains using strain meter data. McCrae *et al.* (1991) highlighted the long-term stability of the vibrating wire instruments in dams. Saetta *et al.* (1995) presented the stress-strain analysis of concrete structures exposed to time and space variable thermal loads by using finite element technique. Zhu *et al.* (1999) discussed about thermal the stresses in RCC dams. Conrad *et al.* (2002) presented advanced temperature monitoring system for two RCC dams, viz., *Mujib* and *Wala*. Leguizamao (2003) presented instrumentation plan for La Meil dam including foundation aspects. Wieland *et al.* (2004, 2007) presented the importance of safety aspects of seismicity in light of RCC dams. Cervera *et al.* (2000) presented a numerical procedure for the simulation of the construction process of RCC dams taking into account the more relevant features of the behavior of concrete at early ages such as hydration, aging, creep and damage. Luna and Wu (2000) presented the simulation of temperature and stress fields during RCC dam construction. Noorzaei *et al*. (2003) investigated the influence of placement schedule on the thermal stresses of RCC dams.

Malkawi *et al.* (2004) presented the computational analysis of thermal and structural stresses of RCC gravity dams. Noorzaei *et al.* (2006) reported the thermal and stress analysis of Kinta RCC dam. A finite element code was applied to the real full scale problem to determine the impact of the placement schedule on the thermal response of roller compacted concrete dam by Jaafar *et al.* (2007). Conrad *et al.* (2007) described the innovative monitoring devices for an integral observation of thermal stress behavior of large RCC dams. Raphel (2008) presented the development of the stresses in Shasta Dam. Cai *et al.* (2008) reported the finite element fracture modeling of concrete gravity dams. The actual climatic conditions and thermal properties of the materials were considered in their analysis. Greyling and Shaw (2010) evaluated Changuinola- I dam for thermal behavior. Rahimi and Noorzaei (2011) presented a thermal and structural analysis of RCC dams by finite element method with respect to the evaluation of the heat generated in the body of the dam during and after construction of the RCC dams. Fujun *et al.* (2012) presented the numerical analysis for the temperature stress distribution in the concrete overflow dam for Hadashan hydro-project using 3-D FEM. Kurian *et al.* (2013) presented the numerical analysis of a temperature distribution across the cross section of a concrete dam located at Perunthenaruvi in India during its early ages.

There are some considerable numbers of studies available in the literature which tried to predict the structural and thermal behavior of the RCC dam through different numerical models and theoretical analyses. Notwithstanding, there is relatively less literature available which describes the instrumentation for monitoring the thermal and structural behavior of such dams. The middle Vaitarana is the first highest dam of its kind constructed in India and provided with extensive instrumentation for round the clock monitoring of the thermo-structural behavior of the RCC prior and after construction. Further, the work that reports the monitoring of the thermal and structural response of RCC dams with the help of considerable instrumentation and validating the results obtained from internal embedded instruments system is hardly available. On this backdrop, an effort is made in this paper to present state- of- the- art instrumentation provided at MVD. Moreover, the results obtained from the instrumentation are compared with the prevalent theoretical criteria.

4. Key issue in RCC dam

4.1Thermal cracking in RCC

According to Shaw (2007) the placement of the mass concrete requires precautions to minimize cracking. During the hydration process, the cement liberates a substantial amount of heat resulting rise in the temperature of concrete. It often reaches about 40-63℃. It can be avoided by proper temperature control by selecting cementitious material to generate least heat by resorting to the following methods:

(i) by cooling RCC components such as coarse aggregate and fine aggregates using sprinklers.
(ii) placing RCC in cool weather seasons.
(iii) use of low heat cement
(iv) maximum replacement of cement by fly ash.

In thermal analysis, the potential of thermal cracking is studied and the stress analysis is carried out to identify the critical tensile stresses due to temperature gradients.

4.2 Stress analysis

The variables used for the analysis of stresses in the dam includes: Joint spacing, restraint condition, modulus of elasticity, creep effect; and tensile strength. While the first variable, i.e., joint spacing is based on the results of the thermal analysis, the remaining variables can be arrived upon from the RCC test section and laboratory investigations.

4.3 Objectives of instrumentation in RCC dam

- For diagnostic purpose of RCC as mass concrete structure (MCS)
- Instrumentation data are frequently used to obtain engineering information necessary for analyzing and defining the extent of a problem.
- Verification of the design parameters, i.e., verification of the behaviour expected.
- Ascertaining the suitability of new construction technique, i.e., RCC.
- Verification of the continued satisfactory performance.

- For predictive purpose: valid prediction of future behavior of dam.
- For legal purpose: instrumentation data can prove as an aid in determining the causes of adverse events so that proper legal adjudication can be accomplished.
- For Research purpose: data useful for future designs. Such research can lead to advances in construction techniques, improved and innovative design concepts; and better understanding of failure mechanisms and adoption of corrective measures.

5. Instruments

The instruments to be used in monitoring the thermo-structural response of the RCC dam should have sufficient accuracy, long term reliability and stability. While they require low maintenance, they should be compatible with the construction techniques. Moreover, they should be simple but rugged.

5.1 Working principle of instruments

The mechanical instrument converts physical change into corresponding mechanical output signals that can be read either by dial gauge, simple scale or Vernier device. The hydraulic devices are filled with de-aired hydraulic fluid. The pneumatic devices are filled with nitrogen. Most of the electrical and electronic instruments work on strain measuring technology. The elastic resistance of a metallic wire changes proportionally to change in its length in resistance type of instruments. The vibrating wire type of instruments works on the principle that the plucked frequency of stretched wire depends on the tension in the wire and hence on the strain. Basic measurement is in the form of frequency**.** The observations can be relayed over long distances through cables without affecting their accuracy.

5.2 Types of measurements for major hydraulic structures

5.2.1 Obligatory measurements

It include the uplift pressure at the base of dam, seepage, temperature –temperature during construction temperature of dam interior, temperature of reservoir water and air, displacement between two monoliths, between foundation and body of the dam, displacement of any joint of the dam with respect to surrounding set up.

5.2.2 Optional measurements

They may be undertaken where warranted by special circumstances of the project, especially provided in high dams, mass concrete structure (MCS) with unusual design or with geological complexities. These measurements are sometimes taken for verification of design criteria, e.g., stress , thermal stress data, thermal response such as strains, pore pressure, seismicity of the area and dynamic characteristics of the structures.

5.2.3 Other meteorological measurements

It includes wind velocity, relative humidity and solar radiation.

5.2.4 Routine measurements

The measurements for reservoir level, precipitation, evaporation and humidity form part of such measurements.

5.3 Planning of instrumentation system for RCC gravity dam

The instruments should be provided at least on deepest overflow (OF) and two non-overflow (NOF) blocks near abutments. The number of blocks to be instrumented should be increased depending upon the length of dam and geological complexities. Further, the aspect of the selection of proper types of instruments along with their location and interpretation is more important than the number of devices to be installed.

Fig. 2 shows the longitudinal section of the middle Vaitarana dam (MVD) showing contraction joints and instrumentation scheme.

Fig. 3 shows the non-overflow and overflow section with thermocouples locations embedded at various levels and around galleries.

The particulars of the instruments and locations as provided at the MVD are shown in Table 1.

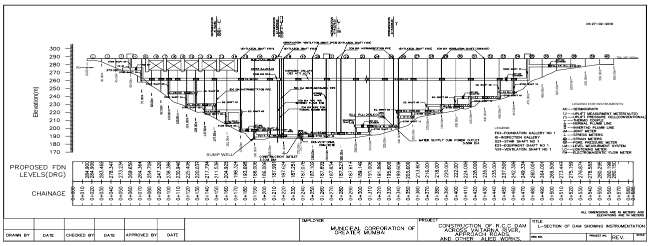


Fig. 2 Longitudinal section of MVD showing contraction joints and instrumentation scheme

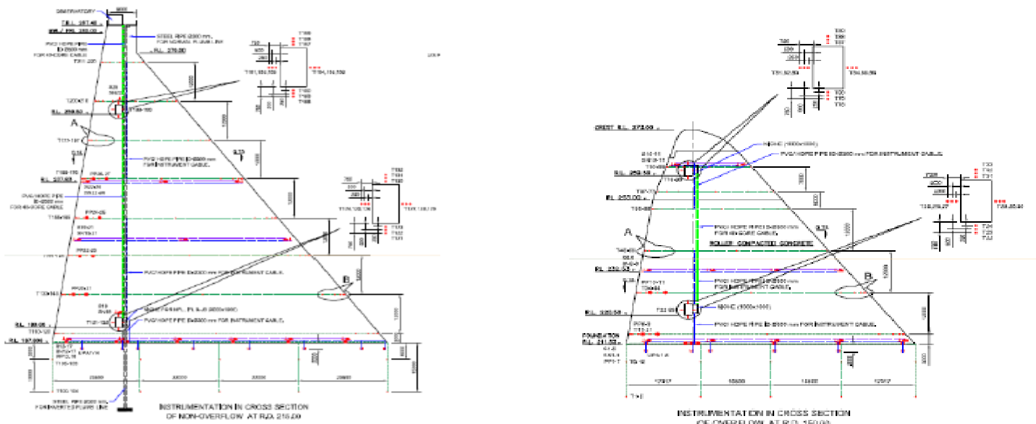


Fig. 3 The non-overflow and overflow section of MVD with locations of thermocouples

Table 1 Instrumentation programme for MVD

Sr.No.	Type of instrument	Nos.
1.	Automatic uplift pressure meter	21
2.	Stress meter	36
3.	Pore pressure meter	20
4.	Strain gauges	36
5.	No stress strain gauge	36
6.	Triaxial Joint meters	36
7.	Inverted plumb line	1
8.	Normal plumb line	1
9.	Thermocouples	428
10.	Seismograph	1
11.	Automatic water level meter (radar type)	1
12.	Flow meters	2
13.	V-notches	4
14.	Automatic weather monitoring station	1
15.	DAS System with SCADA	1

5.3.1 Automated Data Acquisition System (ADAS)

The automated data acquisition system have evolved significantly over last 15 years and are currently installed over large number of dams all over the world. The design of successful ADAS requires considerable efforts. The ADAS system (Fig. 4) ranges from simple use of a data logger to collect data from a few instruments to a computer based system that collect, reduce, present and interpret the data from a network of hundreds of different instruments. It has an advantage of reduced manpower costs for collecting and assimilation of remote data. Similarly, rapid notification of potentially hazardous performance and increased frequency of measurements can be taken on demand.

As the construction progresses, the cables have to be extended with the concrete layers up to junction –cum switch boxes with LPU s' located inside the respective galleries. The readings can, then, be taken easily from each sensor one by one through the switch box. As regards the instrumentation provided at MVD, forty numbers of core cables are used to further connect the switch box to the measurement cabin –cum- control room on the dam top at EL 287.40.

As stated above, the instruments are provided at four sections along the total length of 565 m of the dam, i.e., RD150 m, RD 210.8 m, RD 275 m and RD 335 m, respectively. The observations are taken once daily at 0800Hrs. Some of the observations such as thermo-couple readings are recorded on hourly basis, other climatologically data is automatically stored in ADAS and further, transmitted to central control facility via supervisory control and data acquisition system (SCADA) and V-Sat system installed at the dam site.

5.3.2 Stress meters

The dam is provided with 36 stress meters meant for the measurement of stresses in the dam body and for observing the structural behavior of dam as a mass concrete structure (MCS). Similarly, it is possible to verify the stresses obtained by analytical and experimental methods and more rigorous finite element or thermal analysis. The actual stress distribution pattern resulting from imposed loads can be established.

5.3.3 Strain meters

The vibrating wire type strain meters are installed for measurement and monitoring of the compressive and tensile strain; and its distribution and variation with respect to time. Similarly, the actual structural behavior of mass concrete structure becomes known. The readings are taken once in a day at 0800 Hrs. Its unit is micro strain (reading $\times 10^{-6}$). Each group of reading contains six values out of which one is no stress-strain value and five other strain values are in different directions. Generally, compression is indicated by negative (-) sign and tension, positive (+).

5.3.3.1 Analysis / interpretation

The values in five directions are calculated by deducting no stress-strain value from each of them. Then, using the relation between the corrected strain value and E (modulus of elasticity) the stresses are evaluated. The values, thus, obtained are compared with the calculated stresses against the design values of stresses at the location of strain meters or strain gauges.

5.3.4 Triaxial joint meters

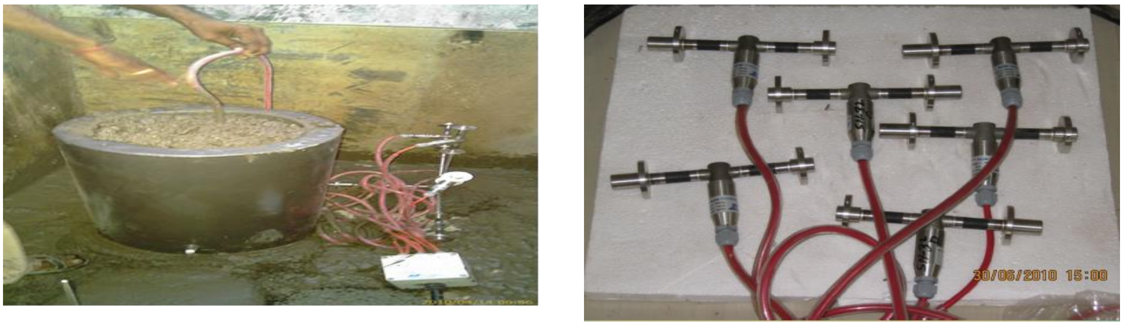
Vibrating wire type model EDJ-40 T of Encardio Rite joint meters (Fig. 5) are installed mainly for the measurement of movement, monitoring of cracks in concrete in addition to the measurement of mass movements in construction joints in the dam. All the three readings for each joint meter are taken, X- reading (longitudinal) and Y- readings (transverse). Similarly, the reading for expansion is regarded as +ve indicating the crack is widening thereby inducing tension and vice - versa. The observations are taken manually with read out units and the readings are in mm.

5.3.5 Normal and inverted plumb line

The normal and inverted plumb lines (Fig. 6) are provided for monitoring tilt of the dam and also, relative displacement in concrete dam between dam top and its base in addition to the relative displacement between the base and the foundation rock. Its reading can be positive or negative which gives movement values in mm.

5.4 Seismic loads

Seismic measuring devices record the intensity and duration of the earthquake. The dam site is located in tectonically active area and lies in earthquake zone -III. The strong seismic motion instrumentation records acceleration from earthquake shaking. The data is used to evaluate the dynamic response of the dam. The seismic acceleration and velocity are usually recorded with the strong –motion accelerographs. These devices typically consist of three mutually perpendicular accelerometers, a recording system; and triggering mechanism. The devices must be properly maintained so that they operate if an earthquake occurs.



(a) Joint meter being installed (b) Accessories of joint meter

Fig. 5 Triaxial joint meter

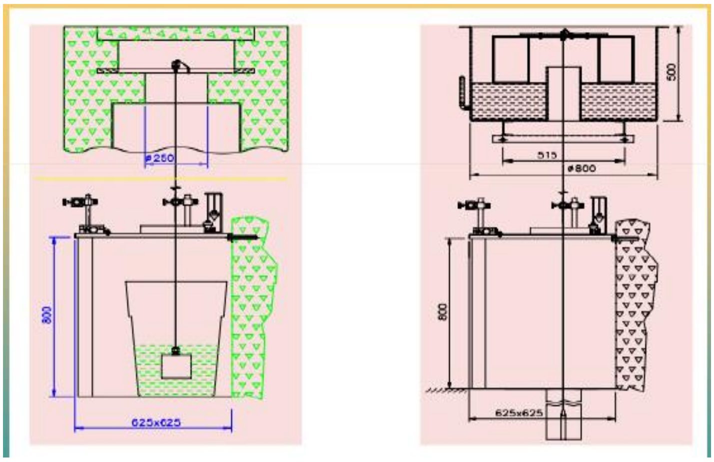


Fig. 6 Installation diagram of Normal and inverted plumb line

5.5 Temperature

The internal temperature of concrete dam is necessary to be measured both-during and after construction. Temperature measurements are important both to determine causes of movement due to expansion or contraction and to compute actual movement. Temperature measurement of dam, foundation or instruments is often required to reduce data from the instruments, increase precision or to interpret results. The movements of concrete dams and changes in leakage at concrete dams are commonly related to the changes in temperature. The temperature is commonly measured in concrete dams under construction to evaluate mix design, placement rates; and monolith or block spacing and lift thicknesses in addition to finalizing the zero stress temperatures and evaluation of thermal loads. The temperatures can be measured with resistance thermometers or thermocouple. The operation and limitations of these devices needs to be studied properly.

5.5.1 Thermocouples

In all, total 428 thermocouples are installed progressively at different locations in four sections as stated in one of the previous sub-sections. A typical thermocouple installed at dam site for recording temperature is shown in Fig. 7. Fig. 8 shows the embedment of the wire of thermocouple in one of the layers. The read out unit showing thermocouple reading is seen in Fig. 9 while the pressure cell embedded in freshly laid RCC layer is shown in Fig. 10.

Fig. 7 Thermocouple

Fig. 8 Embedment of the thermocouple wire

Fig. 9 Read out unit

Fig. 10 Pressure cell

The foundation rock and galleries are provided with additional thermocouples. The junction boxes at inspection galleries are used to record hourly temperature variation in the dam body and its surface. These temperature changes cause thermal stresses in the dam body and surface in addition to the displacement, joint opening and strains. It is based on the principal that the contact potential between the two dissimilar metals varies with the temperature of their junction. Thermal EMF is measured. The readings are taken in degree Celsius using readout units at foundation gallery, inspection gallery and dam top. Only readings are not available in ADAS unlike other instruments. The data can be used for the validation of thermal models and ascertaining placing temperature of roller compacted concrete (RCC) during construction stage.

6. Results and discussion

The observations of the variation in temperature with respect to time as recorded by the thermocouples located at various sections of middle Vaitarna dam are indicated graphically and discussed in this section. The variation in temperature across the RCC layer with age (in months) from the placement of RCC is shown in Fig. 11 whereas the variation in temperature in the horizontal direction during various months from the placement of RCC is shown in Fig. 12.

The data acquired from the thermocouples and presented as above shows rise in the adiabatic temperature up to 35℃ at a typical cross section. All the data is plotted on the cross section of dam and isotherms are developed. This shows the development of thermal gradient in the core of the dam with maximum temperature of 45℃ when the placement temperature was kept as 23.50℃ over a period of three years. The readings of the temperature, as recorded by the thermocouples, show consistent trend and are compatible with the tropical environmental conditions prevailing at the site of the middle Vaitarna dam.

The variation in ambient temperature with months recorded by automatic whether monitoring station installed at the site is shown in Fig. 13. It shows the variation in minimum, maximum and the average values of the temperature. The hourly temperature variation is also shown in Fig. 14.

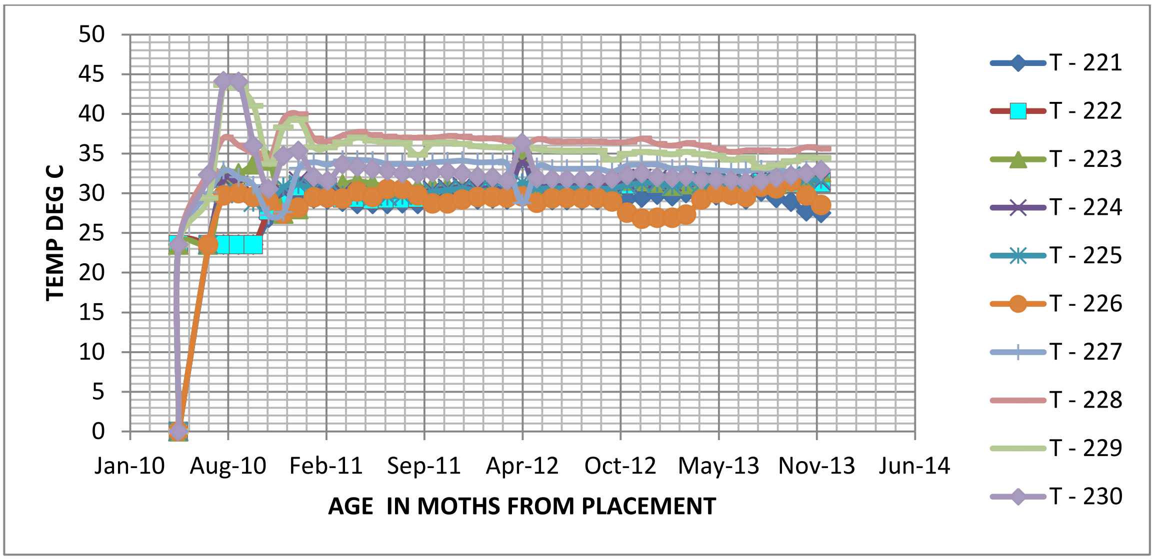


Fig. 11 Temperature -time history across RCC layer as recorded by thermocouples

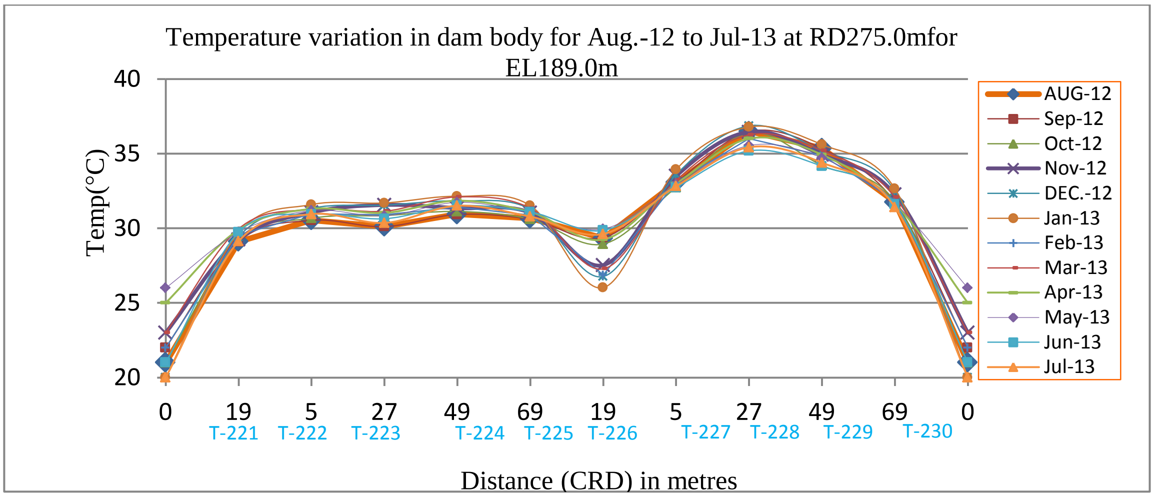


Fig. 12 Variation in temperature in horizontal direction within dam body during various months

The maximum adiabatic temperature of 48℃ is recorded by the thermocouples installed across the cross-section of the dam at the end of the construction period which is three years (1095 days) and is found in the central core of the RCC at about one third of dam height, i.e., at 33 m from the foundation, as is evident from Figs. 15 and 16.

The output and the thermocouple data recorded throughout the construction period of four years is presented in terms of isotherms and shown in Figs. 15 and 16. Fig. 15 indicates the isotherms for the non-overflow section at three different sections, i.e., at RD 150 m, RD 210.8 m and 275 m whereas Fig. 16 shows the isotherms for the overflow section at RD 315 m.

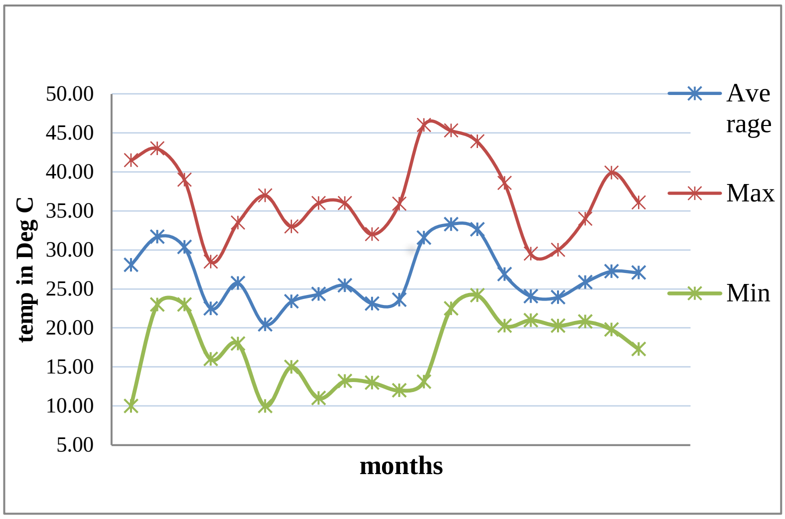


Fig. 13 Variation in ambient temperature variation with months

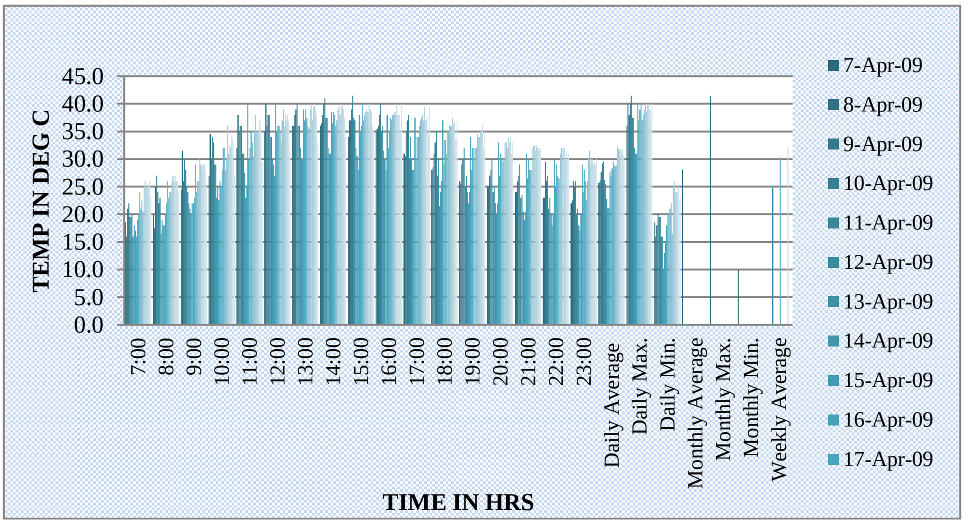
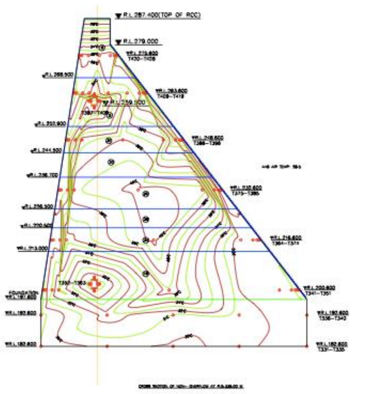
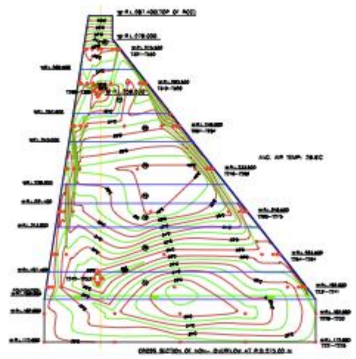


Fig. 14 Hourly temperature variation

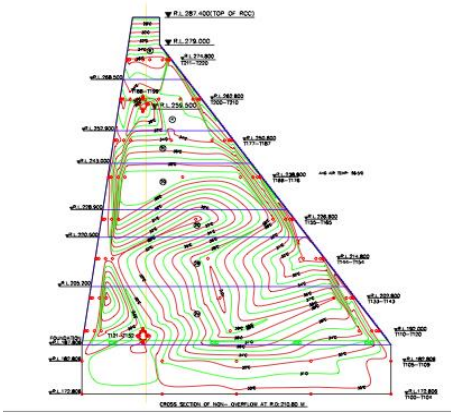
The rise in adiabatic temperature is found to be around 24.50℃ as compared to the initial placement temperature of 23.5℃. The most critical zone seems to be 10 m above the foundation where the restraint is highest and effect of the heat loss from foundation begins to decrease significantly. In order to avoid thermal cracks in this zone, the maximum placing temperature shall not exceed beyond 23.5℃. The surface temperature recorded by the thermocouples near the dam surface is nearly equal to the ambient air temperature and is observed to be varying with the month.



(a) Isotherms at RD 150 m



(b) Isotherms at RD 210.8 m



(c) Isotherms at RD 275 m

Fig. 15 Isotherms as recorded by the thermocouples at various record distances (RDs) in non-overflow section at the end of construction period

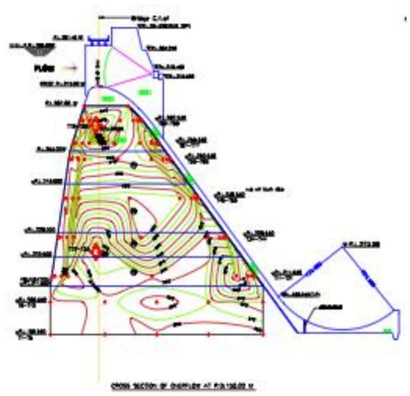


Fig. 16 Isotherms as recorded by the thermocouples at RD 315 m in the overflow section

The horizontal temperature profiles indicate the development of large thermal gradients in the center core of dam rather than outer surface max temp reached is 47-48℃ when the placing temperature was maintained at 23.5℃. This rise in temperature stabilizes slowly over the years. The vertical stress distribution shows some large areas of tensile stress developing in the center of the dam, in the areas surrounding the galleries and the spillway. In addition, the upstream and downstream faces show some potential areas where cracking could potentially develop produced by the lower ambient temperatures during the winter period. Using the actual placement schedule and actual boundary condition in finite element analysis, modeling can be done and will certainly lead to accurately determine the actual maximum temperature developed in the dam body

The temperature in the interior core of a RCC gravity dam drops very slowly, cracks may appear on the upstream and downstream face especially in the winter; thus, some measures must be taken to prevent these cracks. The most effective measure is to insulate the concrete surface.

The readings recorded by the triaxial joint meter taken in all the three directions, with respect to two conditions, namely- dam empty and dam full are shown in Table 2. The negative value indicates the compression.

From the observations of the triaxial joint meters as shown in Table 2, it is seen that the dam section is in compression for dam empty as well as dam full condition. Thus, the design criterion that no section of the dam should be subjected to tension gets fulfilled. Further, the observations as recorded by a typical stress- strain meters for either condition of the dam, i.e., dam empty and dam full are shown in Table 3.

The development of stress during dam empty and full condition shows increase in stress values by 17.81 percent but is in compression as expected. The increase in inside dam temperature is on higher side in conventional concrete used in spillway section as compared to that in fly ash based RCC. The adiabatic temperature rise recorded by thermocouple readings in crest of overflow section is higher than that in RCC since conventional concrete (CVC) is used for this portion as anticipated. At gallery locations, the horizontal temperature profiles recorded shows drop in temperature gradient around the galleries.

Table 2 Observations of triaxial joint meters for dam empty and dam full condition

Joint meter and direction	Dam empty condition		Dam full condition		Remarks
	Values (mm)	Temp. (℃)	Values (mm)	Temp. (℃)	
JM1 - X	-0.20	-	-0.40	-	Compression
JM1 - Y	-0.40	-	-0.20	-	
JM1 -Z	-0.40	29.50	-0.60	34	
JM2- X	-0.10	-	-0.20	-	
JM2- Y	-0.40	-	-0.40	-	
JM2-Z	-0.50	29.60	-0.60	29	
JM3- X	-0.10	-	-0.10	-	
JM3- Y	-0.10	-	-0.20	-	
JM3-Z	-0.50	29.80	-0.50	29	

Table 3 Typical stress- strain meters observations

Sr. No.	Location RD 210.80 m	Stress (MPa) corresponding to different conditions of the dam		Remarks
		Dam full	Dam empty (E=22600 MPa)	
1	Upstream	-3.7328	-2.9670	Compressive
		-7.5060	-6.3640	
		-5.2570	-3.8460	
		-5.8460	-4.7390	
		-4.9680	-3.7760	
2	Upstream	-5.2830	-4.8220	
		-8.7950	-8.3250	
		-7.8370	-7.1390	
		-6.1030	-5.0100	

7. Conclusions

The instrumentation, proper monitoring and the evaluation are extremely valuable in determining the performance of a RCC dam. Understanding of the structural and thermal behavior of the roller compacted concrete as a mass concrete structure is important. The paper provides comprehensive information about the methodology and installation of the instrumentation scheme for monitoring the thermo-structural behavior of RCC dam constructed by MCGM near Mumbai. The common types of instruments for measuring different parameters with its significance are summarized in the paper. Further, performance of the instrumentation during construction and post construction stage of RCC structure is evaluated. The thermal and structural behavior of the middle Vaitarana dam (MVD) as observed through instrumentation provided thereat is compared with the design considerations and satisfactory agreement is observed in the actual behavior and design criteria. Moreover, the instrumentation provided at the RCC dam site is helpful in validating theories and assumptions used in the design and improving upon design principles and discarding erroneous concepts. In addition to this, the long term behavior of RCC dams as mass concrete structures can be predicted and suitable corrective measures can be designed in time. The MVD RCC Dam is the classical example of state-of- the- art instrumentation and ADAS work in India. This aspect can surely be said to be fully satisfied through detailed instrumentation provided at the MVD site. Further, the numerical modeling accounting thermal analysis or non-linear incremental structural analysis (NISA) coupled with thermal analysis using two or three dimensional finite element method could be useful for predicting the anticipated cracking in view of long-term adiabatic rise in temperature for such large mass concrete structure.

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Abbreviations

MCGM	Muncipal corporation of greater Mumbai
RCC	Roller compacted concrete
CVC	Conventional concrete
MCS	Mass concrete structures
RD	Record distance
CRD	Record distance from centre