Sustainable Structures and Materials, *Vol. 4, No .2, (2022) 19-28*

DOI: https://doi.org/10.26392/SSM.2022.04.02.019

Temperature Control and Monitoring For Mass Concrete in Raft under Hot Weather Condition – An Indian Case Study

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(Received October 29, 2021, Revised February 8, 2022, Accepted February 15, 2022)

ABSTRACT. *The temperature difference between inner and outer zones of mass concrete possess a great risk and may induce stresses leading to cracking in the concrete. To avoid the problems associated with temperature-induced stresses in mass concrete, temperature control and monitoring is essential. This paper presents a case study of a raft constructed for a 19 storey residential tower in Delhi, India. In this study, various temperature control methods were adopted at the site during material selection, concrete mixing, transporting, casting and curing. Based on recorded data it was found that adopted measures helped in controlling the peak temperature of the concrete as well as the temperature differences in different sections of the concrete. In total, ten thermal sensors were used in the study. Out of which three sensors were embedded at the top, three at the middle and three at the bottom of the foundation. Apart from these, one thermal sensor was kept in ambient temperature conditions for comparison purposes. In the present study, the temperature differences between the top, middle and bottom of the concrete is primarily focused on. The maximum temperature observed in concrete was 65.50 °C and the maximum temperature difference between top and core of concrete was 14.40 °C, both are within specified limits of 70 °C and 20 °C respectively as per the Indian standard code provisions.*

Keywords: Temperature Control and Monitoring, Heat of Hydration, Mass Concrete, Raft foundation, Thermocouple.

1.0 INTRODUCTION

According to ACI 116R; mass concrete can be defined as "any volume of concrete with dimensions larger to require that measures be taken to cope with generation of heat from hydration of cement and attendant volume change to minimize cracking" [1]. Generally, structural members with a least dimension greater than 1.22 m fall into this category. The early-age temperature generation in mass concrete structures leads to serious impact on its durability. The temperature differential of high magnitude in such structures can result in large temperature-induced stresses which can cause cracking particularly at early age [2]–[5]. The high temperature differential is mainly caused by a large amount of heat generated, due to hydration of cementitious product, in the core of structure that is dissipated at a very slow pace or is not dissipated at localized region, representing a true adiabatic condition [6]–[9].

The temperature regime in mass concrete structures is affected by many factors, such as ambient temperature, wind speed, water temperature, intensity of solar radiation and shading effect, temperature of foundation, and especially amount of hydration heat which is caused by the cement type and its quantity [10]–[12]. In addition, the temperature distribution in the mass concrete is also influenced by other factors, such as schedule of placement, size of aggregate used in mass concrete, initial temperature of concrete mix, curing condition, etc. As a result, high temperature gradient occurring during the construction may cause significant tensile stresses and lead to thermal cracks [13]–[15]. The temperature difference between the inner zone and the outer surface of the mass concrete is the reason causing the formation of thermal stress. If the tensile stress is larger than the tensile strength of the mass concrete, thermal cracks form on the surface of the concrete structure, especially at the early age. In order to avoid the formation of thermal cracks, a general condition is that the temperature gradient ΔT should not exceed 20°C and peak temperature should not exceed 70°C [16].

On other aspect, to minimize the temperature difference between the inner zone and the outer surface of mass concrete causing thermal cracks, past researches indicated several curing methods by using different types of insulation material together with its thickness, such as polystyrene[10] and sand layers [17]. In addition, cooling pipe system is quite a perfect solution to reduce hydration heat in the core of mass concrete [18]. In the present study, temperature gradients between inner and outer zones of mass concrete with is investigated and the temperature profile with time and its maximum value is presented.

In recent years a number of studies have been done to study and control the adverse effects of excessive temperature gradients in mass concrete work. These studies involve various experimental as well as simulation-based approach. By utilizing a Distributed Temperature Sensing (DTS) technology, J. Ouyang et al.[19] proposes a framework for cracking control for a mass concrete structure in a reservoir project. The study demonstrated that the DTS system with fiber optic cable may be used to provide a novel platform for cracking control for a gigantic concrete building under construction. This cracking control is primarily reliant on thermal stress modelling, which is in turn reliant on the values and parameters of the concrete's thermal and mechanical characteristics. The temperature field and temperature time histories for the core concrete of the enormous pier induced by hydration heat were studied by Y. Huang et al. [20] using a 1:5 scaled segmental model test of an arch bridge. Study suggests that the temperature of the concrete climbs rapidly but falls slowly. The temperature gradients between the center and the surfaces of sections were found to be between 25°C to 30°C. Through a three-dimensional finite-element simulation of the hydration heat in concrete with a forced cooling system, Singh, P. R., & Rai, D. C.[21] accurately predicted the experimentally observed temperature profile. The study also showed experimentally that forced cooling helps reduce the interior temperature but, it leads to a reverse thermal gradient around the cooling pipe.

2.0 MATERIALS

The project involved the construction of a multistoried RCC residential building (19 Storey’s). The temperature control and monitoring were studied on a raft foundation located at Tower 9. The size of the raft for the pouring of concrete was 25.4 m x 9.5 m x 1.8 m. A total of 388 cubic meters of concrete was done. The grade of concrete used was M30 and its constituents are presented in Table-1. Reduction of the heat of hydration with different proportions by using fly ash is well documented in past research [22]–[24]. The heat of hydration in concrete using fly ash as a partial substitution of cement is influenced by many parameters, such as the ambient temperature in the curing climate, the amount of cement, the amount of fly ash, and the chemical composition and fineness of the cement and fly ash [25]. In the present study, to minimize the heat of hydration the replacement of cement OPC 43 Grade was done with 20 percent flyash keeping in view the strength requirements of concrete and other durability considerations like carbonation as the structure is constructed in non-coastal and semi-arid environmental conditions. Generally, to control crack, the maximum difference in temperature shall be within the concrete mass should not exceed 20°C [26], but when limestone aggregate is used, the difference can be allowed up to 31°C [27]. The petrographic studies conducted on the coarse aggregate used in construction indicated that the aggregate sample is granite with a crystalline texture and the aim was to maintain the maximum difference in temperature within 20°C. Figure 1 shows the reinforcement of the raft before concreting. As shown in the figure the raft was at some depth from the ground level. It also shows the top reinforcement of the raft and reinforcement for columns and shear walls to be constructed above the foundation in future.

Table-1: Various Constituents of M30 grade of Concrete

Sr. No	Content	For 1 cubic meter
1.	Cement-OPC 43 grade	310 kg
2.	Fly Ash	78 kg
3.	Water	147 litres
4.	Sand	674 kg
5.	Coarse Aggregate 10mm	546 kg
6.	Coarse Aggregate 20mm	724 kg
7.	Admixture	2.33 litres

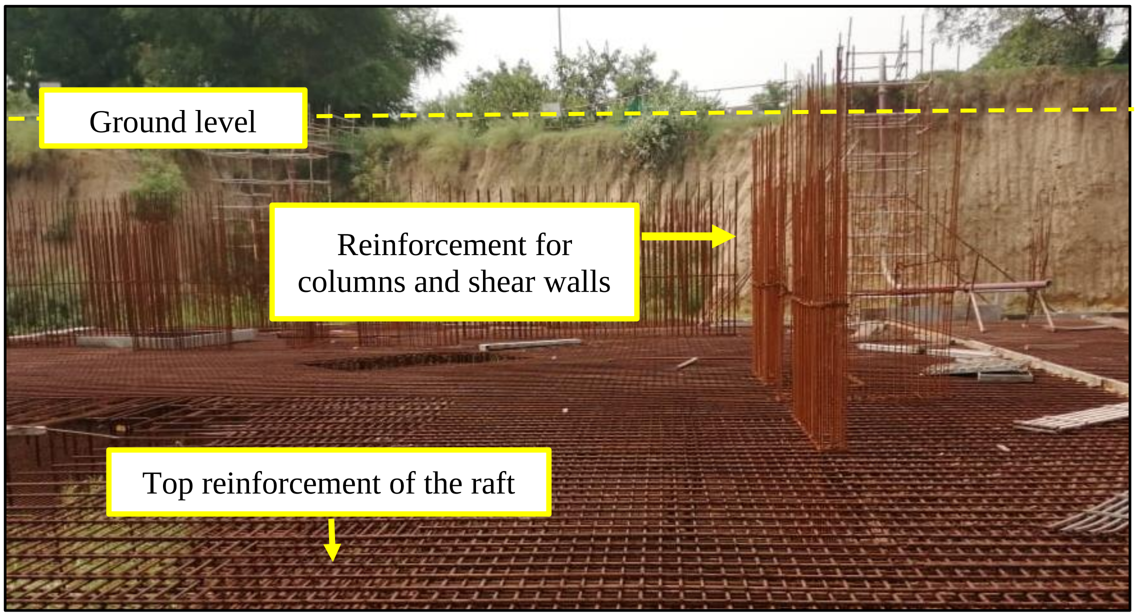


Fig-1: Reinforcement of raft before concreting.

3.0 TEMPERATURE CONTROL

Temperature control is one of the most essential aspects of mass concrete work. It becomes much more important in hot weather conditions. This study was conducted at a site in Delhi during June - July when the daily temperature goes as high as 50 °C. Therefore, appropriate temperature control measures were adopted.

First of all, (a) During material selection, OPC 43 grade of cement was selected and substitution by 20 percent flyash was done which leads to less heat of hydration than OPC 53 grade of cement as already established in past studies (20, 21 & 22). Before casting of concrete (b.) formwork and casting surface was damped with cold water. (c) Coldwater was also sprinkled on the aggregates. (d) Water that was to be used for the concrete mix was cooled by adding ice flakes. (e) The transit mixers transporting concrete from the batching plant to the site were wrapped with hessian cloth and the wrapping was frequently wetted/moistened to reduce the temperature of concrete while transportation. (f) The concrete pipeline from the pump to the pouring location was also wrapped with hessian cloth and the same was periodically wetted to reduce the heat while pumping the concrete. (g) As far as possible, concrete was done during the evening-night/colder atmosphere to avoid the development of shrinkage and thermal cracks. (h) Care was also taken to minimize the time of transportation and pumping of the concrete within the specified retention period of the slump of concrete. (i)After casting, the concrete was covered with polythene sheets to prevent the evaporation of moisture to avoid the formation of shrinkage cracks. (j)To further reduce the differential temperature, water curing was avoided and the curing compound was applied on the horizontal and vertical surfaces of the concrete. (k) After application of the curing compound on the top surface of the raft, it was then covered with polythene sheets and thermocol sheets to prevent dissipation of heat. Figure – 2 shows the schematic sketch of Temperature Control by application of thermocol sheet and curing compound. Figure – 3 shows the application of curing compound and placement of thermocol sheets at the site. The sides of formwork were de-shuttered on the second day – coated with curing compound and again placed in a position to act as an insulated covering to prevent surface temperature loss. The formwork was kept in place for 7 days.

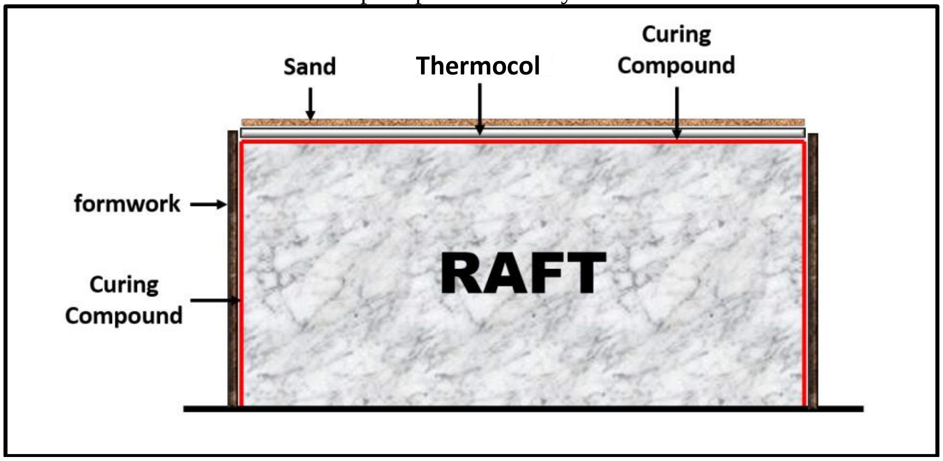


Fig - 2: Temperature Control by application of thermocol sheet and curing compound

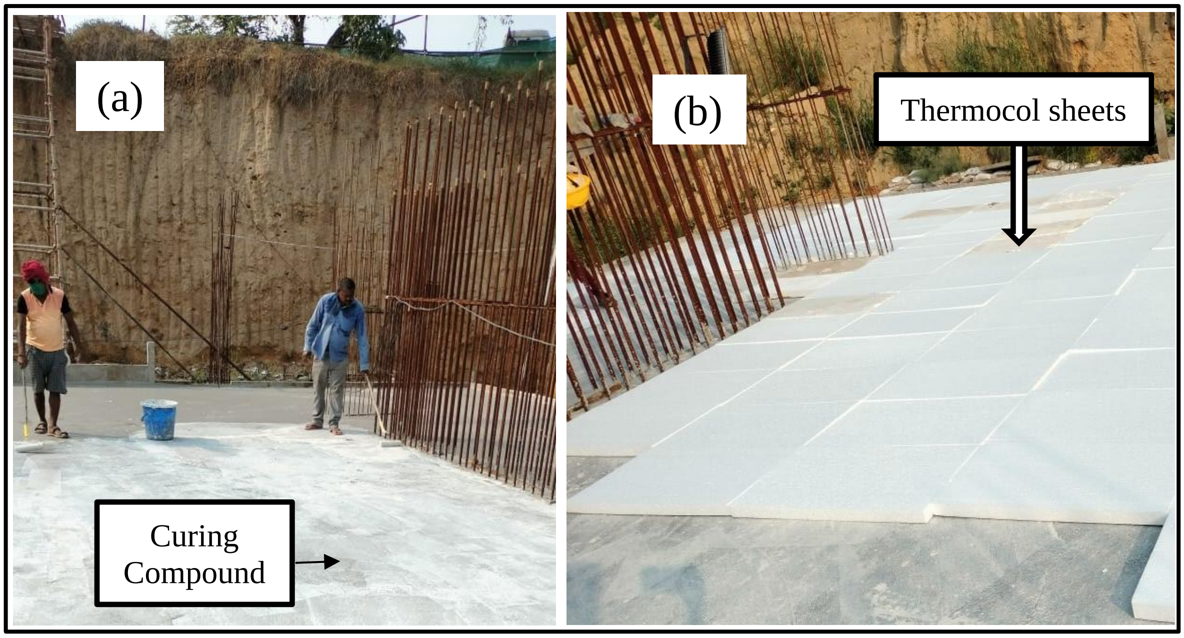


Fig - 3: (a.) Application of curing compound in progress at the site
(b.) Laying of thermocol sheets over the curing compound at the site

4.0 TEMPERATURE MONITORING

The temperature differentials, between core and midpoints of top surface and surface nearest to the core in a rectangular mass concrete raft, are critical for thermal cracking. The temperature development at these three locations is necessary to be monitored. These sections give the details of equipment like the thermal logger and thermal sensor used and explain the location of sensors, and the data captured in the study for temperature monitoring.

4.1 Equipment

Equipment used for temperature monitoring in this study includes a thermal logger and temperature sensors. Through thermal logger received data from the sensors was saved directly on a USB Pen drive as an MS Excel compatible file. The logger had an internal real-time clock with battery backup making it possible to save values along with date and time. Temperature Sensors used in the study had a metallic body and was directly embedded in concrete. It gave Linear output and was capable of working in a temperature range of 20°C to 150°C. It had an Accuracy of ± 0.2°C and a Resolution of 0.1°C. Figure-5 shows the sensor data logger and embedded thermal sensors at the site.

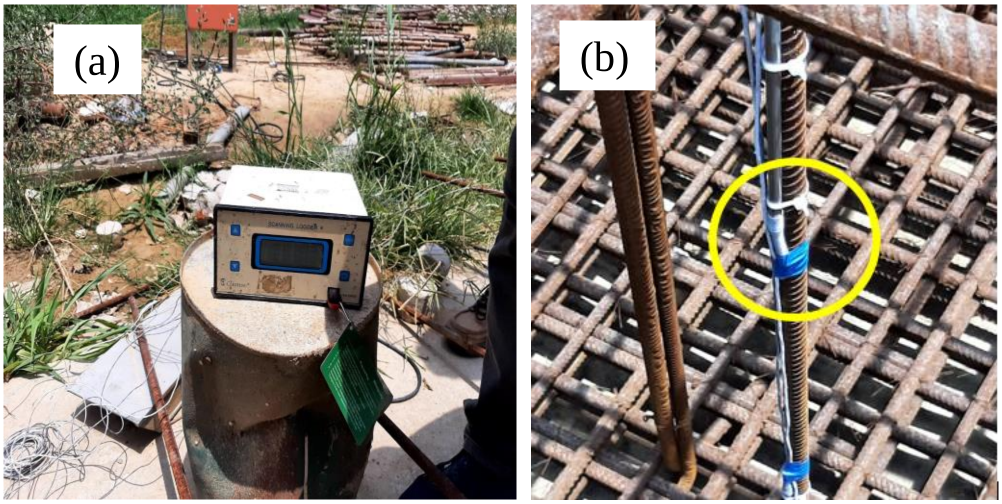


Fig - 4: (a.) Sensor Data Logger used at site **(b.)** Temperature Sensor embedded in raft reinforcement at core location (L1)

4.2 Location of sensors

Temperature monitoring study was conducted in concrete pour at tower no. 9 for a raft of size 25.4m x 9.5m x 1.8m at three locations in the raft i.e., at (i) centre – L1, (ii) edge 1 – L2 (iii) edge 2 – L3. A set of three sensors were embedded at each of these locations, i.e., at the top, middle and bottom. The depth of the sensor from the top face of the raft is 150mm, 900mm and 1650mm respectively for the top middle and bottom sensor. In total 10 thermal sensors were used out of which nine were embedded in the concrete as explained and one of the sensors was located outside the raft to capture ambient temperature. Fig 4 (a) shows the plan of the raft where the three locations L1, L2, and L3 are indicated. And Fig 4 (b) shows a sectional view for each locations where three sets of sensors were embedded at the top middle and bottom.

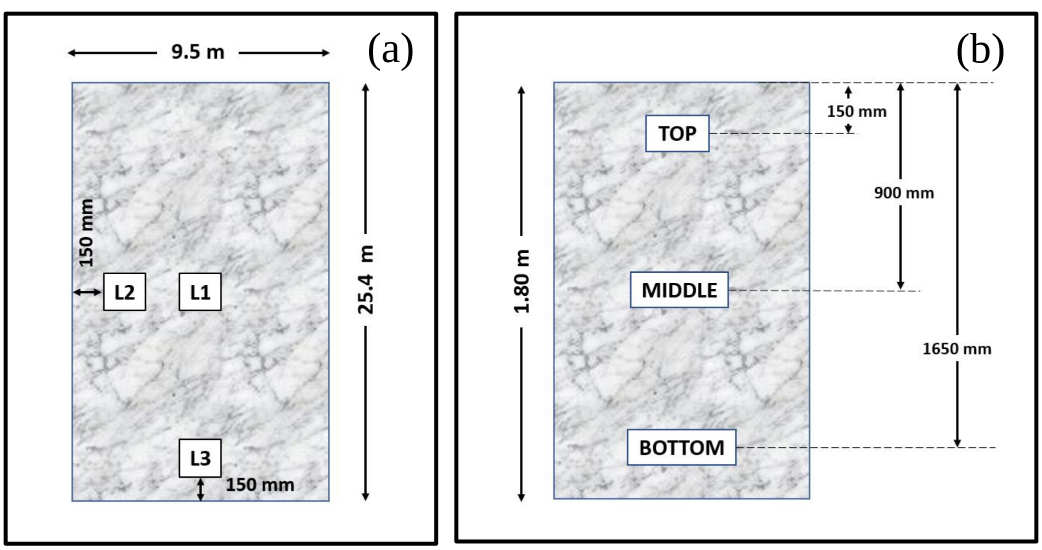


Fig - 5: (a.) Plan of the raft foundation in pour 1B, tower no. 9, indicating the locations of the temperature sensors (Top View) **(b.)** The locations of the sensors in pour 1B, tower no. 9 (Elevation View)

Sensors were located to capture the maximum possible temperature difference in the concrete. For this reason, sensors were located at the edges and the center. Edges can easily dissipate the generated heat as well as are more susceptible to external environmental conditions, on the other hand, the central part of mass concrete is surrounded from all sides by concrete having less opportunity for heat dissipation as well as is isolated from the external environment. Also, the sensors were placed at the top, middle and bottom at each location. This is done because the temperature profile for the top, middle and bottom of the raft was expected to be different. The concreting was also done in layers therefore it was essential to observe the top middle and bottom temperature profile separately.

Table – 2: Location of Sensors and Channels used in Data Logger

S.No.	Locations		Top	Middle	Bottom
			150 mm	**900 mm**	**1650 mm**
1	L – 1	Core	Ch 1	Ch 2	Ch 3
2	L – 2	Edge – 1	Ch 4	Ch 5	Ch 6
3	L – 3	Edge – 2	Ch 7	Ch 8	Ch 9
4	Ambient temperature – outside Raft		Ch 10		

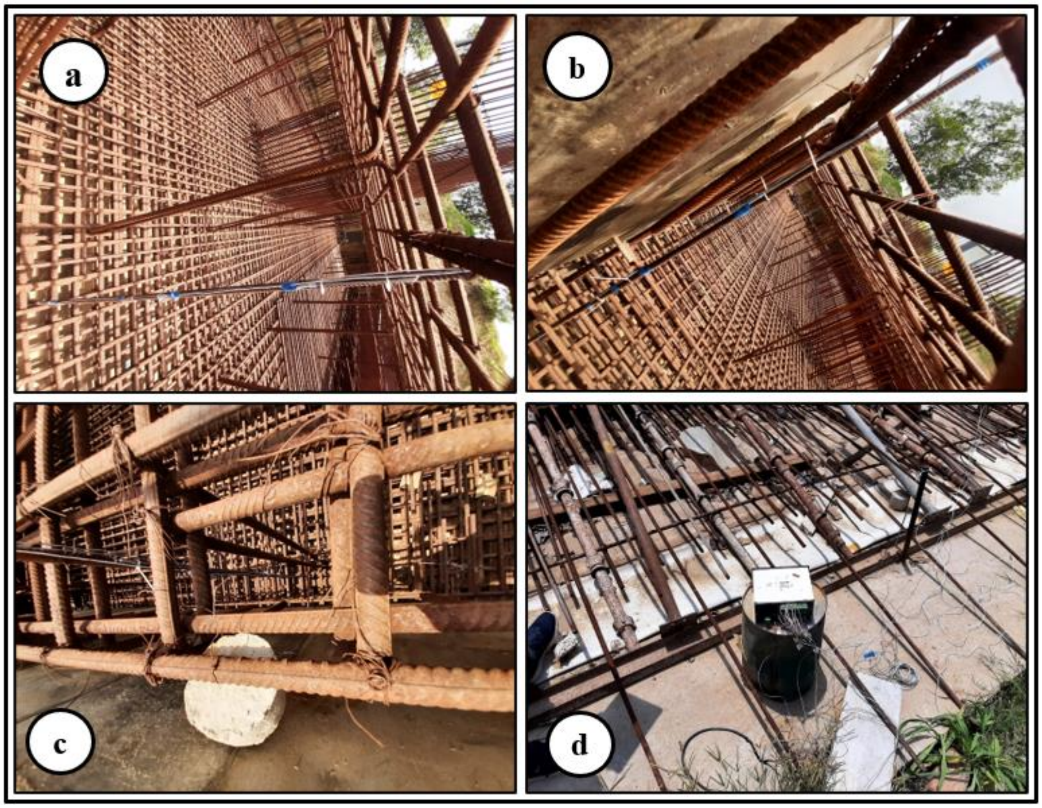


Fig - 6: Showing Thermal sensors **(a.)** at the core, Location L-1
(b.) at the first edge, Location L-2 **(c.)** at the second edge, Location L-3
(d.) outside the raft for ambient temperature

4.3. Concrete Casting and Data capturing

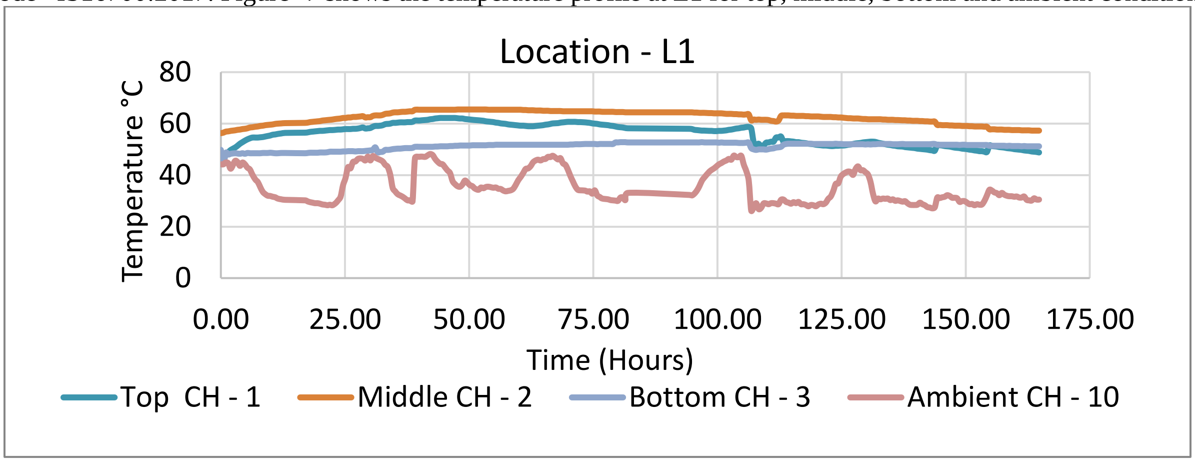
Concrete casting at the site started on June 26th, 2021 at 2:30 pm and continued till June 28th, 2021, at 6:30 am. The sensors and loggers were started on June 26th, 2021, soon after the start of concrete pouring. But the data used for temperature profiling starts from June 28th, 2021, 11:25 am, i.e., after completion of casting and complete insulation work. Readings were taken up to July 6th, 2021. The temperature data before complete casting and installation of insulation was not considered in the study because some of the sensors were open to the environment, and was not embedded in concrete. The whole test was carried out for 8 days after casting and the temperature measurement was carried out at the 30-minute interval. Temperature rise and fall in concrete is relatively a slow process, therefore literature[28] suggested a 2-hour duration for the first 24 hours after casting and a 3-hour duration after that. For more accurate results 30 minutes interval was selected in the study.

5.0 RESULTS AND DISCUSSIONS

Based on the recorded temperature data, temperature profiles with time are plotted for three locations – L1 (centre), L2 (first edge) and L3 (Second edge). For each of these locations temperature profiles are compared for top, middle, and bottom sensors. The following sections discusses the findings at each of these locations.

5.1 Location L 1

The maximum temperature difference observed between the middle and top of location L1 was 11.30 °C on July, 3rd and on July 4th. Also, between the middle and the bottom of location L1 the maximum temperature difference of 14.40 °C was observed on June, 29th. These two values are below the specified limit of 20 °C as per Indian Standard Code –IS16700:2017. Figure -7 shows the temperature profile at L1 for top, middle, bottom and ambient conditions.

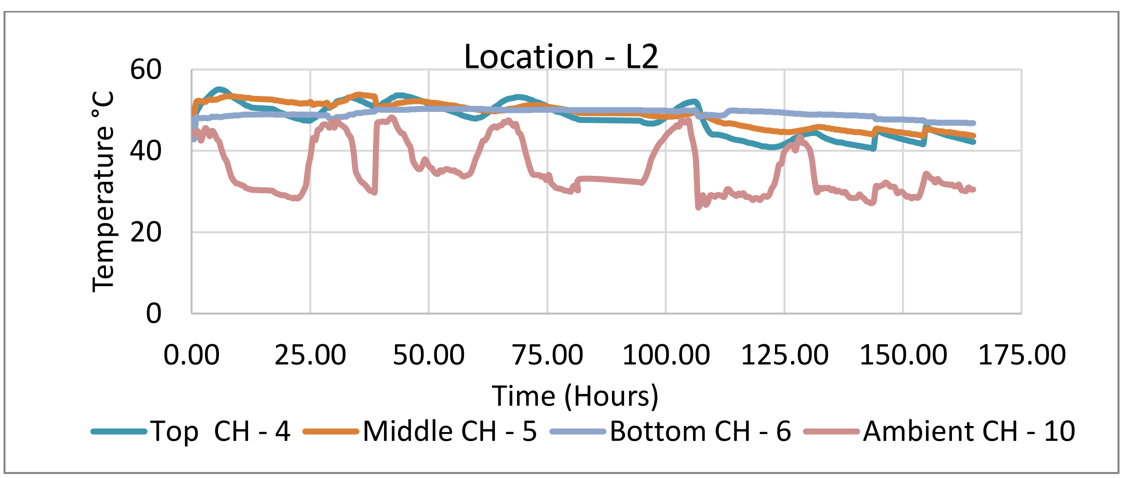


S.No.	Locations	Top	Middle	Bottom
		150 mm	**900 mm**	**1650 mm**
1	**L 1**	Channel 1	Channel – 2	Channel 3

Fig - 7: Graph showing Temperature profile of channels 1, 2, 3 and 10

5.2 Location L 2

For location L2, the maximum temperature difference between the middle and top was found to be 4.50°C. The maximum temperature difference observed between the middle and bottom was 5.80 °C. Here also, the temperature difference is below 20°C, the limit specified by IS16700:2017. The temperature profile for location L2 is shown in fig 8.

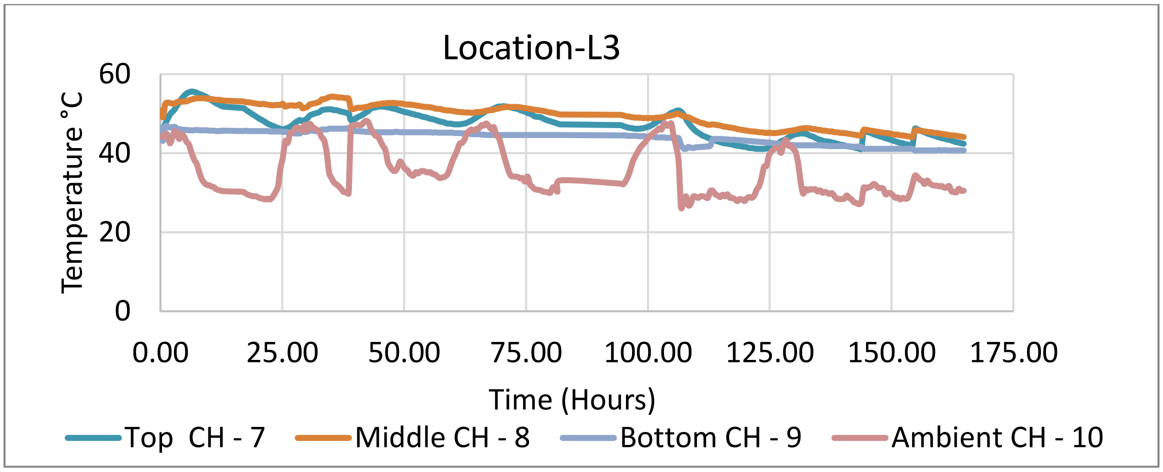


S.No.	Locations	Top	Middle	Bottom
		150 mm	900 mm	1650 mm
2	L 2	Channel 4	Channel 5	Channel 6

Fig - 8: Graph showing Temperature profile of channels 4, 5, 6 and 10

5.3 Location L3

At L3 similar profiles were obtained as L2. The maximum temperature difference between the middle and top of location L3 was 6.5 °C and the maximum temperature difference between at middle and bottom was 8.2 °C. Figure 9 shows the temperature profile for location L3.



S.No.	Locations	Top	Middle	Bottom
		150 mm	900 mm	1650 mm
3	L 3	Channel 7	Channel 8	Channel 9

Fig - 9: Graph showing Temperature profile of channels 7, 8, 9 and 10

The maximum ambient temperature recorded was 48.2°C on June, 30th 2021 and peak temperature in concrete was also recorded as 65.5°C on the same day i.e., June, 30th at location L1 in the middle section (the core of the raft). Table 3 and 4 show the maximum temperature and maximum temperature difference captured in the study. It can be observed from table 4, at edges (L2 and L3) the temperature differences are lower than at the centre (L1). The reason can be attributed to the high amount of temperature generation at the core due to hydration and very little dissipation. Also from comparing the temperature profiles of sensors inside the concrete to the sensor in ambient condition, it can be observed that applied insulation methods in the study are quite effective as they helped top surface to maintain a comparably steady temperature than the varying atmospheric temperature during day and night.

Table – 3: Maximum temperature recorded (in °C)

Maximum temperature in concrete	65.5	On June 30th
Maximum ambient Temperature	48.2	On June 30th

Table – 4: Maximum temperature difference between sections (in °C)

Difference Between	Location			Maximum
	L1	L2	L3	
Top - Middle	11.30	4.50	6.50	11.30
Middle - Bottom	14.40	5.80	8.20	14.40

6.0 CONCLUSIONS

This study presented a case study of temperature control and monitoring of mass concrete raft at a site in Delhi, India during June –July 2021, when the maximum daily temperature was around 40°C to 50 °C. Temperature monitoring data of mass concrete raft shows that, adopting temperature control measures helped in maintaining peak temperature and maximum temperature difference in concrete within limits as given below:

a) Peak temperature in concrete was 65.5 °C at location L1, i.e., at the centre. It is less than the specified limit of 70 °C as per Indian Standard Code –IS16700:2017.
b) The maximum temperature difference between the top and middle section was 11.30 °C, observed at L1 and the maximum temperature difference between bottom and middle was 14.4 °C at L1. These values are within the limits, i.e., less than 20 °C as per Indian Standard Code –IS16700:2017.
c) The study indicates that at edges (L2 and L3), the temperature differences are lower than at the centre (L1).
d) The comparison of temperature profiles of sensors inside the concrete to the sensor in ambient condition indicated that applied insulation methods in the study are quite effective in insulating the top surface to maintain a comparably steady temperature.

The study presented measures which needs to be adopted for concrete casting and temperature control in hot weather conditions. These measures include use of OPC 43 grade cement with fly ash as mineral admixture (fly ash content was 20 % of total cementitious content), addition of ice flakes in mixing water, wrapping of transit mixer during transportation and concrete pumping unit with hessian cloth, pouring of concrete during evening-night (cooler atmospheric conditions), use of polythene sheets to prevent the evaporation of moisture which can lead to shrinkage cracks and application of curing compound on raft top. The results suggests that these measures can help in temperature control of mass concrete work in hot weather conditions.

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