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TEMPERATURE CONTROL & MONITORING OF MASS CONCRETE:

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A B S T R A C T :

The temperature difference between inner and outer zones of mass concrete possesses a great risk and may induce stress 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 Mumbai, 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.

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". Generally, structural members with the least dimension greater than 1.22 m fall into this category. We have limit i.e 1.5 mtr. 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 an early age. 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. 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. 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. 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. 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 in within 72 hours.
On other aspect, to minimize the temperature difference between the inner zone and the outer surface of mass concrete causing thermal cracks, past research indicated several curing methods by using different types of insulation material together with its thickness, such as polystyrene and sand layers. In addition, cooling pipe system is quite a perfect solution to reduce hydration heat in the core of mass concrete. In the present study, temperature gradients between inner and outer zones of mass concrete are investigated and the temperature profile with time and its maximum value is presented.

In recent years several 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 approaches. By utilizing Distributed Temperature Sensing (DTS) technology, J. Ouyang et al. 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. 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, 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

1.1. Need

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 needs 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.

1.2. Scope

Temperature control in concrete construction aims to prevent cracking and ensure structural integrity by managing the heat generated during the hydration process and mitigating the effects of extreme temperatures, especially in mass concrete applications

LITERATURE SURVEY

What is literature survey?

In the context of temperature control in concrete technology, a literature survey involves a comprehensive review of existing research, reports, and standards to understand the current state of knowledge, identify knowledge gaps, and inform the development of effective temperature control strategies.

PROBLEM STATEMENT

The problem statement for temperature control in concrete focuses on preventing or minimizing cracking and durability issues caused by excessive heat generation during the hydration process, especially in large concrete elements, by controlling temperature rise and temperature differences

METHODOLOGY

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 Mumbai during June - July when the daily temperature goes as high as 50 °C. Therefore, appropriate temperature control measures were adopted.

First, (a) During material selection, OPC 43 grade of cement was selected and substitution by 20 percent fly ash 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.

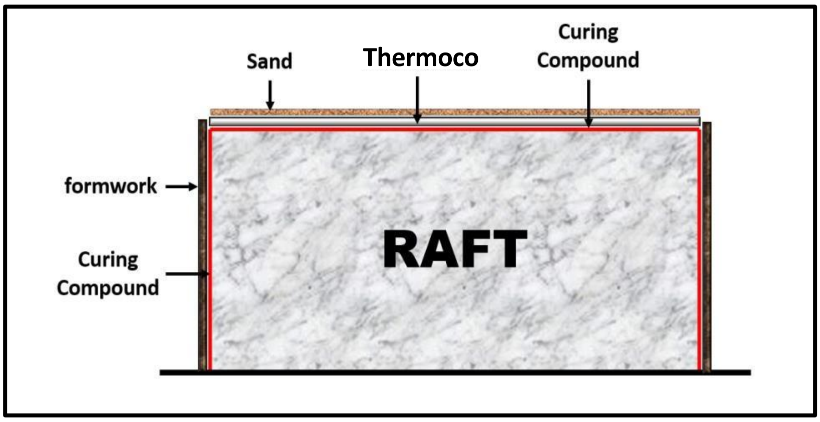


Fig - 1: Temperature Control by application of thermocol sheet and curing compound

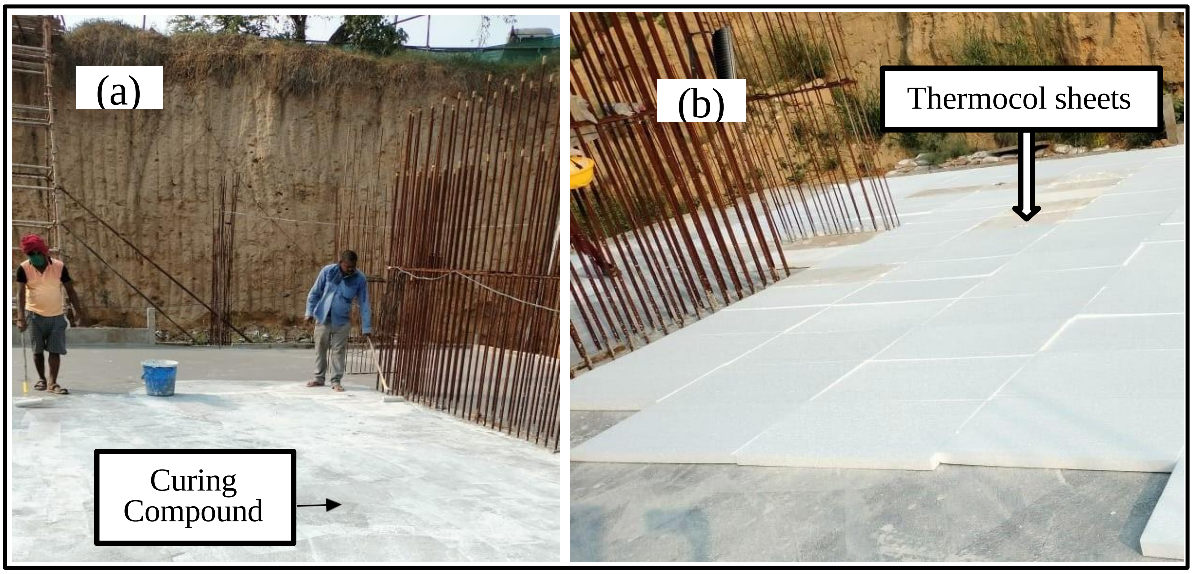


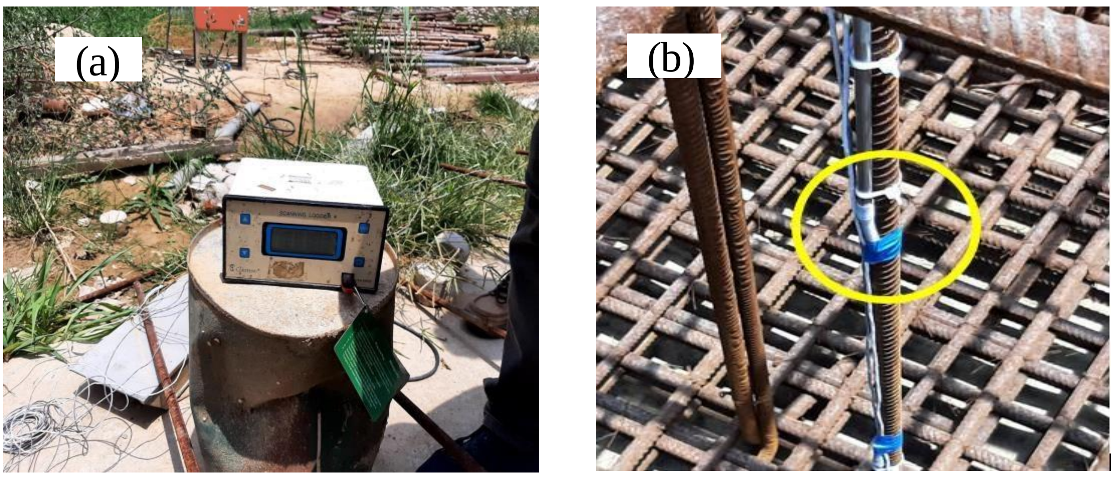
Fig - 2: (a.) Application of curing compound in progress at the site

(b.) Laying of thermocol sheets over the curing compound at the site

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 could work 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 - 3: (a.) Sensor Data Logger used at site (b.) Temperature Sensor embedded in raft reinforcement at core location (L1)



Concrete Casting and Data capturing

Concrete casting at the site started on June 26th, 2024 at 2:30 pm and continued till June 28th, 2024, at 6:30 am. The sensors and loggers were started on June 26th, 2024, soon after the start of concrete pouring. But the data used for temperature profiling starts from June 28th, 2024, 11:25 am, i.e., after completion of casting and complete insulation work. Readings were taken up to July 6th, 2024. 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 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.

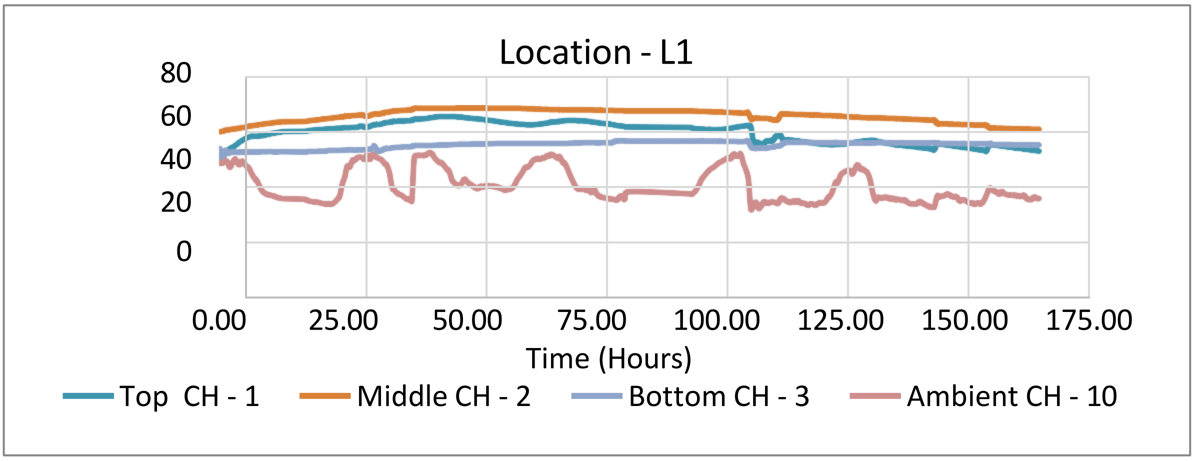
Result & Discussion

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.

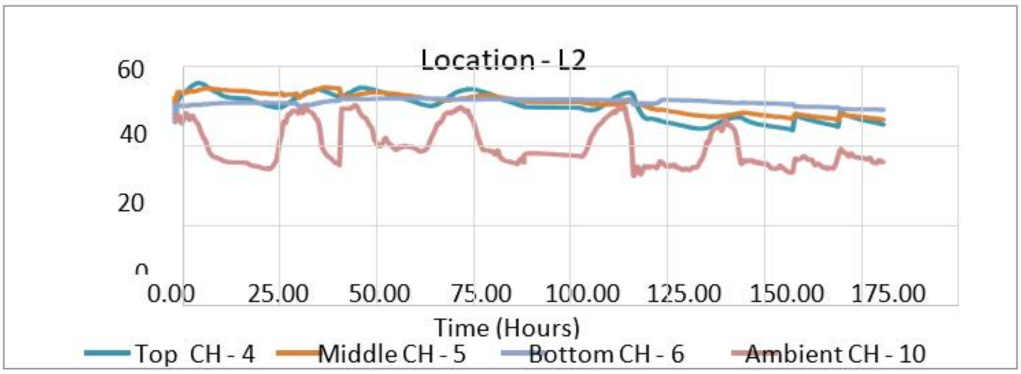
Location of Sensor

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		

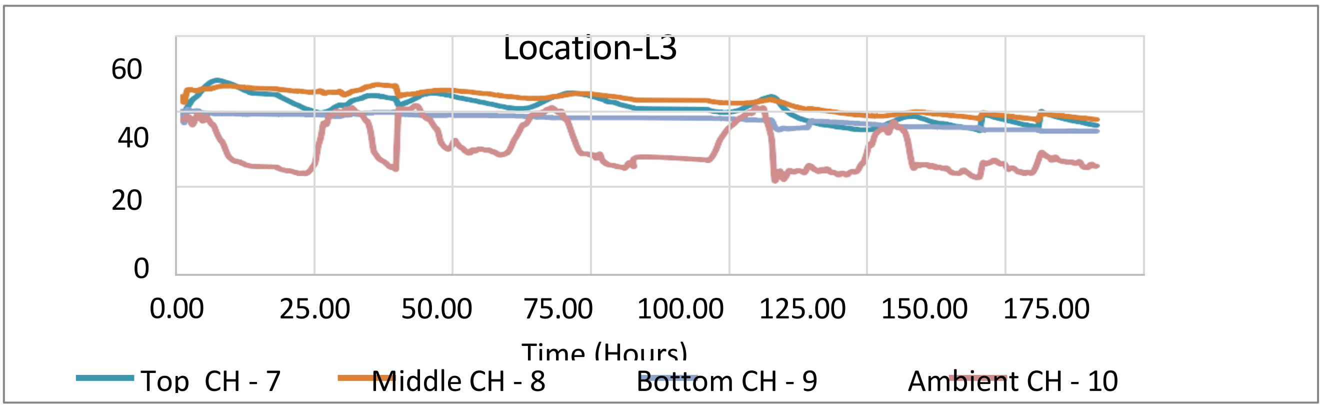
LOCATION 01 SENSOR: - The maximum temperature difference observed between the middle and top of location L1 was 11.30 °C on July, 3rd and on July 4th. Also, between the middle and the bottom of location L1 the maximum temperature difference of 14.40 °C was observed on June, 29th. These two values are 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 condition.



LOCATION 02 SENSOR: - 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.



LOCATION 03 SENSOR: - 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.



Concrete cube casting & Testing: - To test temperature-controlled concrete's strength using the cube method, you cast concrete samples in 150mm x 150mm x 150mm cube molds, cure them under controlled conditions, and then test their compressive strength using a compression machine

Concrete Mix Preparation:

- Proportions: Prepare the concrete mix according to the specified proportions, ensuring the correct cement, aggregate, and water ratios.
- Mixing: Thoroughly mix the concrete to achieve a homogenous consistency.

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

Casting the Cubes:

- Molds: Use standard 150mm x 150mm x 150mm cube molds.
- Filling: Fill the molds with the concrete mix in layers, compacting each layer to remove air voids and ensure proper compaction.
- Compaction: Use a tamping rod or vibrating table to eliminate air bubbles and achieve proper compaction.

Curing:

- Initial Curing:

After casting, allow the cubes to cure in the molds for 24 hours in a controlled environment, preventing drying or cracking.

- Demolding:

Carefully remove the cubes from the molds after the initial curing period.

- Water Curing:

Submerge the cubes in a water tank for further curing, typically for 7 or 28 days, depending on the testing requirements.

Testing:

- Preparation: Before testing, remove any excess water from the cube's surface.
- Compression Machine: Place the cubes in a calibrated compression testing machine.
- Loading: Apply a gradually increasing load to the cubes until they fail.
- Recording: Record the maximum load at which the cube fails, and calculate the compressive strength.
- Testing Times: Cubes are typically tested at 7 and 28 days, but other testing times (3, 5, 14 days, etc.) may be required depending on the project specifications.

In house cube test results.

Sr. No.	GRADE	DOC	DOT	AGE DAYS	WEIGHT, KGS	LOAD, kN	C STRENGTH, MPA	AVG STRENGTH, MPA
1	M30	26-06-2024	29-06-2024	3	8.342	351.0	15.6	
2	M30	26-06-2024	29-06-2024	3	8.426	333.0	14.8	15.3
3	M30	26-06-2024	29-06-2024	3	8.372	346.5	15.4	
4	M30	26-06-2024	03-07-2024	7	8.264	481.5	21.4	
5	M30	26-06-2024	03-07-2024	7	8.376	497.3	22.1	21.8
6	M30	26-06-2024	03-07-2024	7	8.365	492.8	21.9	
7	M30	26-06-2024	24-07-2024	28	8.367	702.0	31.2	
8	M30	26-06-2024	24-07-2024	28	8.356	690.8	30.7	31.1
9	M30	26-06-2024	24-07-2024	28	8.278	704.3	31.3	
10	M30	26-06-2024	21-08-2024	56	8.421	792.0	35.2	
11	M30	26-06-2024	21-08-2024	56	8.344	780.8	34.7	35.4
12	M30	26-06-2024	21-08-2024	56	8.681	816.8	36.3	

Third party Test report:

TEST REPORT NO.	:	BMTD/24/07/00317	DATE : 28/07/2024
Party's Name & Address	:	M/S. GAURAV K. SAWANT, SAMARTH POLYTECH.	
Party's Letter Ref. No.& Date	:	LETTER DATED 24/07/2024	
Sample Described as	:	CONCRETE CUBE	
Date of Receipt of Sample	:	24/07/2024	
Date/s of Analysis	:	---	
Tested to Specification	:	---	
Stamped / Sealed By	:	---	
Analysis No.	:	BMTD/24/07/00317	
Sample ID Mark	:	TEMPERATURE CONTROL CONCRETE	
(as described by Party)		DATE OF CASTING : 26/06/2024	(DAYS - 28)
		GRADE OF CONCRETE : M-30	

DISCIPLINE : MECHANICAL TESTING

GROUP : BUILDING MATERIAL

CURING CONDITION : WATER CURING (27±2°C)

TEST	METHOD/TECHNIQUE	RESULTS	UNIT OF MEASURE
COMPRESSIVE TEST	IS : 516 (PART-1/SEC-1) - 2021	As per below	---

Sr. No.	Size Of Cube (mm)	Cube Age (days)	Cube Wt. (kg)	Compressive Load (KN)	Results Compressive Strength (N/mm²)
Sample 1	149.9 X 150.1 X 149.9	28	8.486	707.0	31.2
Sample 2	150.0 X 150.1 X 150.0	28	8.570	749.3	33.3
Sample 3	150.1 X 149.9 X 150.1	28	8.573	778.5	34.6
			Average		33.0

For GEO-CHEM LABORATORIES PRIVATE LIMITED

SANSKAR MHATRE
Sr. TESTING ENGINEER
(BUILDING MATERIAL TESTING DIVISION)
Authorised Signatory
(Reviewed & Authorised By)

Note : Laboratory is not responsible for sampling, sample is provided by the customer.

ULR No. : TC1153825000371300F

-END OF REPORT-

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RECORD NO. : GCMLD/QR/7.8/02 AMENDMENT NO. : 02 ISSUE NO. : 05 PAGE NO.: 1 OF 1

Conclusion

This study presented a case study of temperature control and monitoring of mass concrete raft at a site in Mumbai, India during June 2024, when the maximum daily temperature was around 30°C to 50 °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 center. 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 center (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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