Smart Monitoring System for Sustainable Infrastructure

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Abstract - **In recent years, the rapid growth of infrastructure and urban development has increased the need for efficient and sustainable monitoring systems. Conventional methods of infrastructure inspection are manual, time-consuming, and lack real-time monitoring capabilities, which may lead to delayed detection of structural issues and increased maintenance costs. To address these challenges, this project presents the development of a Smart Monitoring System for Sustainable Infrastructure using Internet of Things (IoT) technology.**

The proposed system utilizes sensors such as temperature sensors to continuously monitor important structural parameters. These sensors are connected to a microcontroller unit, which collects and processes the data in real time. The collected data is then transmitted to a cloud platform through wireless communication, allowing remote monitoring through a dashboard or mobile application.

The system is designed to generate alerts when the monitored parameters exceed predefined safety limits, enabling early detection of potential structural failures. This helps in reducing maintenance costs, improving safety, and preventing major damages. Additionally, the system supports efficient resource utilization and reduces unnecessary inspections, thereby contributing to sustainable infrastructure management.

The proposed smart monitoring system is cost-effective, reliable, and easy to implement. It can be applied to various types of infrastructure such as bridges, buildings, and water systems. Overall, this project demonstrates how modern technologies like IoT can be effectively used to enhance infrastructure safety, optimize maintenance, and promote long-term sustainability

I.INTRODUCTION

1.1 General

Infrastructure is a vital component of civil engineering, forming the backbone of economic development and societal well-being. Structures such as bridges, buildings, dams, and transportation systems are designed to serve for long periods under varying environmental and loading conditions. However, over time, these structures are subjected to deterioration due to factors such as material aging, environmental exposure, dynamic loads, and natural hazards.

In conventional civil engineering practice, structural health assessment is carried out through periodic inspections and maintenance activities. These methods are often insufficient for detecting early-stage damage and may lead to unsafe conditions or unexpected failures.

With the advancement of technology, modern civil engineering is incorporating smart systems for continuous monitoring of infrastructure. This project focuses on the development of a smart monitoring system that integrates sensors and IoT technology to assess structural behavior in real time, thereby enhancing safety, durability, and sustainability of infrastructure.

1.2 Selection of Study Model

In this project, a prototype model representing a civil engineering structure such as a Raft, beam, bridge model, or building frame is selected. This model is used to simulate real-life structural conditions and to demonstrate the effectiveness of the monitoring system.

1.2.1 Identification of Parameters

The key structural and environmental parameters to be monitored are identified based on their importance in assessing structural health:

- Temperature – to analyze environmental impact on material performance These parameters help in understanding the behavior and safety of the structure.
- Stress/Strain – to evaluate load effects on the structure
- Vibration – to detect dynamic behavior and possible damage

1.2.2 Sensor Selection and Installation

Appropriate sensors are selected for measuring the identified parameters: The sensors are carefully installed on critical points of the structure where maximum stress, heat or movement is expected. Proper placement ensures accurate data collection

- Temperature Sensor

Temperature sensors for analyzing the environmental impact on material performance must offer high precision, long-term stability, and the ability to operate in harsh conditions

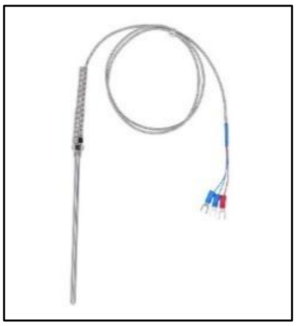

Fig. 1.2.2.1 • Temperature Sensor

- Strain Gauge Sensor

A strain gauge sensor is a device that measures mechanical deformation-strain-by converting force, pressure, or weight into a change in electrical resistance.

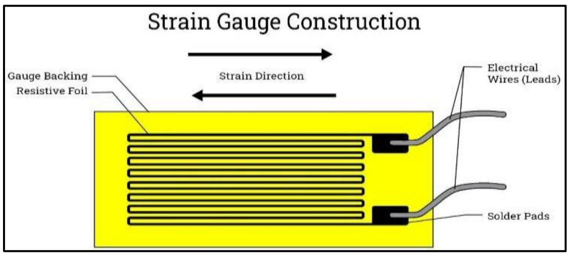

Fig. 1.2.2.2 • Strain Gauge Sensor

- Accelerometer Sensor

An accelerometer sensor is an electromechanical device that measures proper acceleration the rate of change of velocity along one or more axes. It detects both dynamic movement (vibration, acceleration) and static forces (gravity/tilt), commonly using MEMS (Micro- Electro-Mechanical Systems) technology to detect capacitance changes in a proof mass.

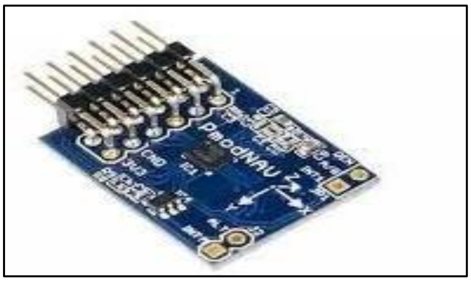

Fig 1.2.2.3 • Accelerometer Sensor

1.2.3 Data Acquisition System

A microcontroller unit such as Arduino Uno or Node MCU, Data Logger is used to collect data from the sensors. The sensors are connected to the microcontroller through appropriate interfaces. The microcontroller reads the sensor signals at regular intervals and converts them into digital data for further processing.

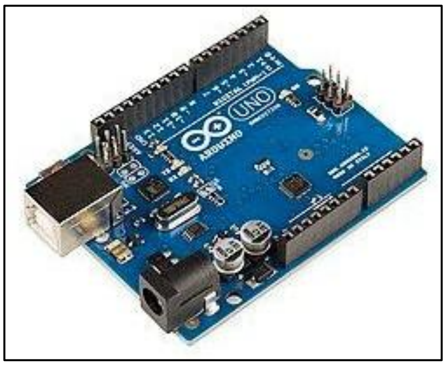

Fig 1.2.3.1 • Arduino

Fig 1.2.3.2 • Node MCU

Fig 1.2.3.3 • Data logger

1.2.4 Data Transmission (IoT Integration)

The collected data is transmitted to a cloud platform using a wireless communication system or wire system:

- Wi-Fi module (in case of Arduino)
- Built-in Wi-Fi (Node MCU)
- Wire Connection

The data is sent to an IoT platform such as:

- Blynk
- ThingSpeak

- Mobile application dashboard
- Pendrive

This enables remote monitoring of structural parameters in real time.

1.2.5 Data Processing and Analysis

The transmitted data is processed and analyzed to evaluate the structural condition. Graphs and charts are generated to observe trends in parameters such as vibration and temperature. Threshold values are predefined based on safe limits. If the measured values exceed these limits, it indicates abnormal structural behavior.

1.2.6 Alert and Notification System

An alert system is incorporated in the project to notify users when unsafe conditions occur. Alerts can be generated in the form of:

- Notifications on mobile applications
- Visual indicators (LED/Buzzer)

This helps in early detection of potential structural failures and enables timely corrective actions.

1.2.7 Result Evaluation

The collected data is analyzed to assess the effectiveness of the monitoring system. The results demonstrate the capability of the system to detect variations in structural parameters and provide real-time monitoring.

1.2.8 Implementation for Sustainable Infrastructure

The developed system can be applied to real-world civil engineering structures such as bridges, buildings, dams, and pipelines. It helps in:

- Improving structural safety
- Reducing maintenance cost
- Enhancing life span of infrastructure
- Supporting sustainable development

1.2.9 Problem Statement

Civil engineering structures are continuously exposed to various loads and environmental conditions that cause gradual deterioration and structural damage. Traditional inspection methods are manual, periodic, and dependent on human judgment, which may result in delayed detection of critical issues such as cracks, excessive deflection, or vibrations.

This delay in identifying structural problems can lead to increased maintenance costs, reduced service life, and in severe cases, structural failure. Moreover, the absence of continuous monitoring makes it difficult to assess real-time structural performance.

Therefore, there is a need for an efficient structural health monitoring system that provides real-time data, ensures early detection of defects, and supports sustainable maintenance practices in civil engineering infrastructure.

1.3 Scope of the Project

The scope of this project lies in the application of smart monitoring techniques in civil engineering structures for assessing their structural health and performance. The system can be implemented in structures such as bridges, buildings, dams, and pavements to monitor critical parameters.

This project demonstrates a prototype model integrated with sensors and data monitoring systems, which can be further scaled for real-life civil engineering applications. It provides a foundation for adopting advanced technologies like IoT and data analytics in infrastructure Management.

However, the current work is limited to basic monitoring and does not include detailed structural analysis or large-scale field implementation. Future scope includes integration with advanced structural analysis tools, artificial intelligence for predictive maintenance, and implementation in smart city infrastructure systems.

1.4 Objective of the Project

1.4.1 To develop a structural health monitoring system for civil infrastructure.

1.4.2 To measure parameters such as temperature.

1.4.3 To provide real-time monitoring and alert system.

1.4.4 Evaluate the importance of temperature control in mass concrete for strength, durability, and crack prevention.

1.4.5 To reduce maintenance cost and improve lifecycle performance.

II.LITERATURE REVIEW

2.1 Literature Review: -

2.1.1 Sharma, A., et al. (2022) – Highlights the role of smart monitoring systems in sustainable infrastructure, focusing on reduced environmental impact and improved efficiency.

Sharma, A., et al. (2022) highlights the role of smart monitoring systems in sustainable infrastructure by focusing on the integration of Internet of Things (IoT) sensors, artificial intelligence (AI), and real-time data analytics to reduce environmental impact and improve efficiency

Key aspects of this research often include:
Reduced Environmental Impact: Smart monitoring allows for early detection of structural anomalies (up to 40% reduced maintenance frequency) and optimizes resource usage, which minimizes the carbon footprint of infrastructure projects.
Improved Efficiency: AI-driven predictive analytics and IoT sensors enable proactive maintenance rather than reactive repairs, significantly improving system reliability and reducing waste.
Application Areas: The research generally spans across smart city infrastructure (highways, bridges, buildings) to agricultural systems, aimed at creating sustainable, resilient urban environments.

2.1.2 Patel, M., et al. (2021) – Explores the use of sensor-based systems in structural monitoring, demonstrating improved accuracy and real-time alerts.

Singh and Patel (2021), in the context of recent advancements in structural health monitoring (SHM), developed a smart monitoring system integrating Internet of Things (IoT) sensors and Artificial Intelligence (AI) for multi-storey buildings
Key aspects of this research include:
Application: The system was designed for the continuous monitoring of structural parameters such as vibration, strain, and temperature in multi-storey structures.
Real-time Capabilities: The system provided real-time alerts regarding structural shifts, allowing for early detection of potential defects and enhancing safety.
Improved Accuracy: By utilizing IoT-based multi-node systems and AI, the approach improved the accuracy of damage detection compared to traditional manual inspections.
Impact: The findings demonstrated that such AI and IoT-enabled systems allow for predictive maintenance, reducing the need for costly manual inspections and enhancing structural resilience.

2.1.3 CSIR Research Report (2021) – Discusses the application of advanced technologies in infrastructure monitoring, improving safety and sustainability

The CSIR Research Report (2020-21) highlights advancements in infrastructure monitoring, utilizing technologies like IoT, UAVs, and smart materials. These interventions enhance structural safety and sustainability, particularly in high-altitude roads, mining, and civil engineering. Key applications include real-time monitoring and digital solutions to improve efficiency
Key Focus Areas of Infrastructure Research (2021) include:
Highway and Transportation Engineering: CSIR-CRRI focuses on developing smart, durable, and cost-effective road infrastructure.
High-Altitude Infrastructure: Geosynthetic-reinforced pavement technologies are developed to withstand extreme climates, utilizing local materials to reduce the carbon footprint.
Structural Health Monitoring: Application of IoT-enabled sensors and drones for real-time monitoring of bridges and structures to detect defects early and prevent hazards.
Sustainable Mining Techniques: Use of UAV-based predictive modelling and robotic monitoring for improved blasting safety and reduced environmental impact.
Smart Materials & Data Analytics: Development of advanced sensors and data analytics to optimize infrastructure monitoring.

2.1.4 World Bank Report (2020) – Emphasizes the importance of smart infrastructure systems for sustainable development and efficient resource utilization.

Investing in sustainable infrastructure helps connect people with opportunities, promotes economic growth, and improves livelihoods. It also provides a pathway for countries to integrate their climate and development goals by investing in projects that reduce carbon footprints, including renewable energy, green transport, and digital ecosystems.

2.1.5 Kumar, R., et al. (2020) – Evaluates low-cost IoT-based monitoring systems for civil structures, highlighting ease of implementation and scalability.

Based on the research, this work (likely referencing studies similar to Kumar et al., 2020, as indexed in the search results regarding "low-cost IoT-based

SHM", such as those found in ResearchGate/Springer papers from 2020-2024 exploring ESP8266 or Xnode systems) generally presents the following:
Low-Cost IoT Approach: The system utilizes affordable, off-the-shelf sensors and microcontrollers (e.g., NODE MCU ESP8266, ADXL accelerometers) to create DIY wireless sensor nodes, reducing the high deployment costs associated with wired structural health monitoring (SHM) systems.
Ease of Implementation & Scalability: The "do-it-yourself" nodes are relatively easy to implement on various civil engineering structures, such as bridges and buildings. The system architecture enables scalability—adding more nodes to monitor different parts of a structure—with data accessible remotely.
Performance Evaluation: These systems track real-time vibration data, acceleration-time history, and environmental factors (temperature, humidity), comparing results with traditional, expensive accelerometers to validate their accuracy and performance.
IoT Paradigm Benefits: The integration with cloud platforms (e.g., ThingSpeak) ensures real-time monitoring and allows for early damage detection, ensuring the longevity and safety of infrastructure.

2.1.6 Li, H., et al. (2019) – Discusses real-time monitoring techniques for civil structures, emphasizing improved durability and early detection of structural issues.

Structural health monitoring (SHM) and damage assessment of civil engineering infrastructure are complex tasks. Structural health and strength of structures are influenced by various factors, such as the material production stage, transportation, placement, workmanship, formwork removal, and concrete curing. Technological advancements and the widespread availability of Wi-Fi networks has resulted in SHM shifting from traditional wire-based methods to Internet of Things (IoT)-based real-time wireless sensors. Comprehensive structural health assessment can be performed through the efficient use of real-time test data on structures obtained from various types of IoT sensors, which monitor several health parameters of structures, available on cloud-based data storage systems. The sensor data may be subsequently used for various applications, such as forecasting masonry construction deterioration, predicting the early-stage compressive strength of concrete, forecasting the optimum time for the removal of formwork, vibration and curing quality control, crack detection in buildings, pothole detection on roads, determination of the construction quality, corrosion diagnosis, identification of various damage typologies and seismic vulnerability assessment. This review paper summarizes the applications of the wireless IoT technology in the monitoring of civil engineering infrastructure. In addition, several case studies on real structures and laboratory investigations for monitoring the structural health of civil engineering constructions are discussed.

2.1.7 Zhang, Y., et al. (2018) – Highlights the integration of cloud computing with structural monitoring systems, enabling remote access and efficient data analysis.

The 2018 work by Zhang et al. (often cited in relation to Internet of Things-based structural health monitoring) highlights the integration of cloud computing with sensor networks to enable real-time, remote structural health monitoring (SHM).
Remote Access and Visualization: The system allows for the monitoring of structural integrity from remote locations, often visualizing real-time structural movements through 3D models accessible via web or mobile devices.
IoT Integration: The framework integrates IoT (Internet of Things) devices with cloud platforms to manage, store, and analyze the large datasets produced by sensors.
Efficient Data Analysis: It facilitates the processing of large volumes of structural monitoring data (e.g., from accelerometers), overcoming limitations of traditional, localized, and wired monitoring systems.
Benefits: This integration addresses challenges such as high installation costs, maintenance difficulties, and the need for high-performance computing in damage identification for civil infrastructure.

2.1.8 International Journal of Engineering Research & Technology (IJERT) (2018) – Presents IoT-based smart monitoring systems for civil engineering applications, highlighting cost-effectiveness and real-time performance.

IJERT (2018) research highlights that IoT-based smart monitoring systems offer cost-effective, real-time, and continuous structural health monitoring (SHM) for civil engineering applications. These systems utilize sensors, Wi-Fi modules, and cloud computing to detect deterioration in harsh environments, allowing for remote data access and improved maintenance efficiency, such as identifying damage location and width in structures.

Application Areas: These systems are particularly effective for structural health monitoring of buildings, bridges, and other infrastructure exposed to harsh environments.
Components & Performance: Systems often use microcontrollers (e.g., Arduino/Pro-Trinket) and wireless communication modules (Wi-Fi, RF) to send data to the cloud, allowing for remote, real-time monitoring.
Cost-Effectiveness: The use of IoT reduces the need for constant on-site inspections, creating, in many cases, a low-cost, low-power, and flexible alternative to traditional monitoring methods.
Benefits: Enhanced safety, early detection of damage, and improved maintenance management are the primary benefits of implementing these smart sensors.

2.2 Literature survey summary: -
The reviewed literature indicates that structural health monitoring using sensors and IoT technology plays a significant role in modern civil engineering. Various researchers have demonstrated that real-time monitoring systems improve structural safety, enhance durability, and reduce maintenance costs. The use of wireless sensor networks and cloud-based platforms enables continuous data collection and efficient analysis.
Furthermore, these systems support sustainable infrastructure by optimizing resource utilization and minimizing environmental impact. However, many existing systems are complex and expensive, which limits their practical implementation. Therefore, this project focuses on developing a cost-effective and efficient smart monitoring system suitable for real-world civil engineering applications.

III.METHODOLOGY

3.1 Project methodology
The methodology of this project focuses on the development of a smart monitoring system for sustainable infrastructure using sensor-based and Internet of Things (IoT) technology. The study involves the selection of a structural model and identification of key parameters such as temperature, which I essential for evaluating structural health. Sensors are installed at critical locations on the structure, and the collected data is processed using a microcontroller such as data logger.
The processed data is transmitted with a pen drive for real- time monitoring and analysis. Threshold values are defined to detect abnormal conditions. The system is tested under different conditions to evaluate its performance, ensuring improved safety, reduced Results and Analysis, maintenance cost, and sustainable infrastructure management.

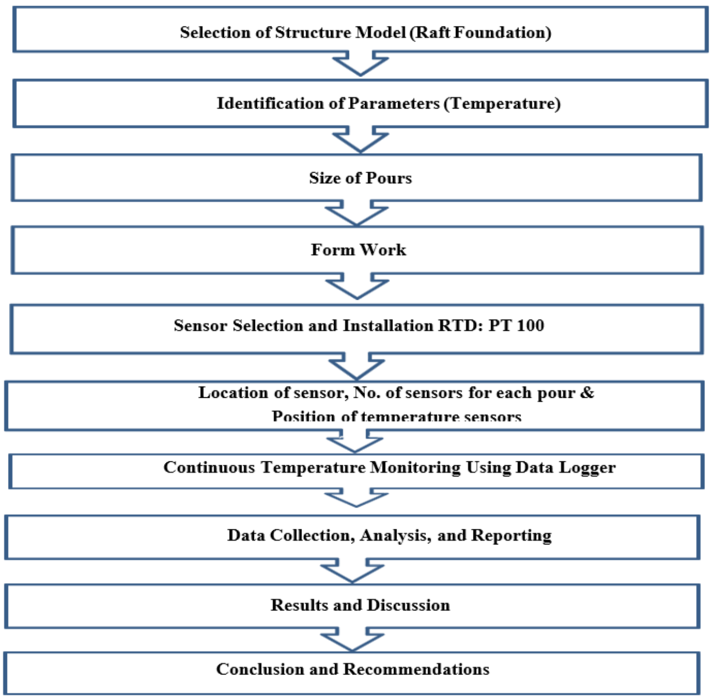

Fig. 3.1.1 Methodology

IV.EXPERIMENTAL PROGRAMME

4. 1 METHODOLOGY FOR TEMPERATURE MONITORING OF RAFT

Table no. 4.1: Information of Temperature Monitoring

Information of Temperature Monitoring		
1	Name & project address	CCI Project, Rivali park, Borivali (East)
2	Structural element	Tower-3, Pour-4A
3	Estimated Concrete Quantity (Cum)	190
4	Actual Concrete consumed (Cum)	168
5	Number of temperature sensors	7
6	Concrete temperature (^{0}C)	25
7	Ambient Temperature (^{0}C)	29
8	Type of insulation	Curing Compound & double layer PP sheet

Table no. 4.2: Concrete Mix Design Details

Concrete Mix Design Details			
Grade: M50 TCC			
Sr. No	Ingredient	Source	Quantity (Kg/Cum)
1	Cement	Orient	250
2	GGBS	JSW	250
3	Flyash	-	
4	Crush aggregate	Wada	709
5	CA I (10mm)	Wada	618
6	CA II (20mm)	Wada	511
7	ICE	Poul Cold & Chirag Ice	
8	ICE Water	Bore well	160
9	Admixture	Infra.Market	6.2

Selection of Structure Model (Raft Foundation)

Fig. 4.1.1 • Site Visit

Fig. 4.1.2 • Location of Raft Foundation

4. 2 Objective of study

a. To understand the maximum core temperature and temperature gradients for mass concrete application for given grades of mixes to be used in the project which will help in accepting /redesigning mixes developed.

4. 3 Size of Pours

a. Concrete blocks / foundations shall be cast of specified size with proposed grades
of concrete.

4. 4 Form work: -

a. 25 mm thick plywood box with appropriate support system.

b. Top portion cover with PU sheet (20 mm thick) or Polystyrene sheets (25 mm thick), thermocol sheets (40mm thick) use for insulation preferably the actual insulation indented to be used.

c. Cover the top surface over the thermal sheets by 300-gauge plastic sheet.

4. 5 Location of sensor

a. Sensor shall be provided as shown in the following sketch

4. 6 Temperature sensor with data Logger

a. Temperature sensors: RTD: PT 100

4. 7 No. of sensors for each pour: 7 (Please see below sketch)

a. 6 in concrete plus one for ambient temperature

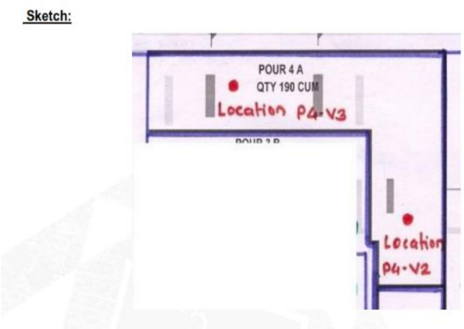

Fig. 4.7.1 _ Sensors Location Sketch

4. 8 Position of temperature sensors:

Table no. 4.3

Sensor no.	Location
1	V3 bottom
2	V3 middle
3	V3 top
4	V4 bottom
5	V4 middle
6	V4 top
7	Ambient

Note: Sensor No. 1 to 6 are consumables

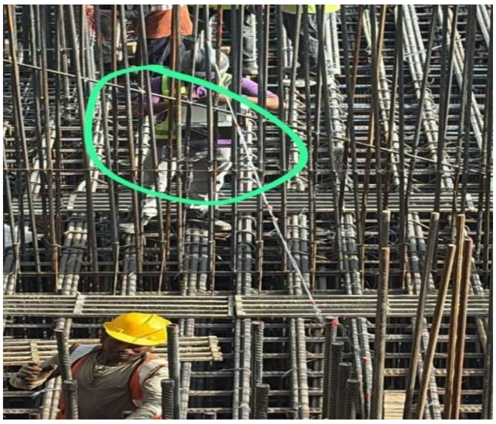

Fig. 4.8.1 • Fixing of Data Logger

4. 9 Sensor's cable will have sleeves from cable connecting end to protect from damage and from electromagnetic interference leaving the sensor exposed.

4. 10 Sensor cables will be connected to data logger for continuous monitoring of temperature, for 7 days from the time of pouring of concrete. At the end of monitoring period, data from data logger will be downloaded to PC, analyzed and report submitted with observations.

Fig. 4.10.1 • Fixing of Ambient Sensor to Data Logger

Fig 4.10.2- Installation of Sensor

Fig 4.10.3- Concrete Temperature Checking at the time of Pour

Table no. 4.4 – Report

Time in hrs	V3 bottom	V3 middle	V3 top	V4 bottom	V4 middle	V4 top	Ambient	Gradient of V3	Gradient of V4
0:00:00	28.7	28.2	28.1	29	28.3	28.2	28.1	0.6	0.8
0:30:00	29.3	28.5	28.6	27.2	28.3	28.6	28.6	0.8	1.4
1:00:00	29.7	29	29	27.9	29	29	29.2	0.7	1.1
1:30:00	29.7	29.2	29.2	28.4	29.2	29.1	29.1	0.5	0.8
2:00:00	30.1	29.5	29.4	28.9	29.7	29.4	29.7	0.7	0.8
2:30:00	26.9	29.2	29.4	29.3	29.8	29.4	29.7	2.5	0.5
3:00:00	27.3	29.2	29.4	29.7	30.1	29.5	29.7	2.1	0.6
3:30:00	27.6	29.2	29.4	30.4	30.2	29.4	30.9	1.8	1
4:00:00	27.9	28.6	29	31.1	30	28.8	31.2	1.1	2.3
4:30:00	28.4	28.6	29.4	32	30.6	29.4	31.5	1	2.6
5:00:00	28.9	29.2	30	33	28.5	29.5	31.7	1.1	4.5
5:30:00	29.3	29.4	31	34.2	29.8	29.7	31.6	1.7	4.5
6:00:00	29.7	29	32.2	35.1	30.3	29.2	32.5	3.2	5.9
6:30:00	30.1	28.8	31.5	36.2	31	28.8	31.6	2.7	7.4
7:00:00	30.6	28.8	30.9	37.5	31.9	29.4	31.6	2.1	8.1
7:30:00	31.3	26.6	29.6	39	32.7	29.7	32.2	4.7	9.3
8:00:00	32	27.3	28.1	40	33.6	28.4	28.8	4.7	11.6
8:30:00	33	28	28.8	40.9	34.6	29.3	31.3	5	11.6
9:00:00	30	28.6	29.4	41.3	35.5	29.8	32	1.4	11.5
9:30:00	29.7	29.2	29.4	41.6	36.5	29.8	32.1	0.5	11.8
10:00:00	30.8	29.8	29.5	42	37.5	29.8	32.2	1.3	12.2
10:30:00	32.9	30.3	24.6	42.9	38.5	29.9	29.6	8.3	13
11:00:00	33.6	31	25.1	43.3	39.6	30.2	29.7	8.5	13.1
11:30:00	33.2	31.9	23.9	43.3	40.6	29.6	29.9	9.3	13.7
12:00:00	35.4	33	25.4	44.1	41.6	25.3	30.2	10	18.8
12:30:00	36.7	34.2	25.9	44.3	42.4	25.6	29.8	10.8	18.7
13:00:00	37.3	35.4	25.7	44.7	43.2	26	28.7	11.6	18.7
13:30:00	38	36.8	24.1	44.9	43.9	26.6	29.1	13.9	18.3
14:00:00	38.5	38.3	23.2	45.2	44.6	27.2	28	15.3	18
14:30:00	39	39.8	24	45.6	45.2	27.7	28.5	15.8	17.9
15:00:00	38.9	41.2	21.3	45.6	45.7	28.1	29.5	19.9	17.6
15:30:00	39.6	42.3	24.1	46.1	46.4	28.6	29.2	18.2	17.8
16:00:00	40.1	43.2	24.8	46.3	46.9	29.1	29.4	18.4	17.8
16:30:00	40.5	43.9	25.4	46.6	46.9	29.8	29.3	18.5	17.1

17:00:00	40.8	44.5	25.9	46.8	47.5	30.5	29.3	18.6	17
17:30:00	41.1	45.1	26.8	47.1	48.1	31.5	28.7	18.3	16.6
18:00:00	41.3	45.5	27.1	47.2	48.5	32.5	29.1	18.4	16
18:30:00	41.7	46	28.9	47.6	49.2	33.5	29.4	17.1	15.7
19:00:00	42	46.5	29.4	47.7	49.4	34.5	29.4	17.1	14.9
19:30:00	41.6	46.5	27.4	47.6	49.6	35.6	29.4	19.1	14
20:00:00	42.6	46.7	31.1	48	50.2	36.8	29.2	15.6	13.4
20:30:00	42.6	47.1	31.7	48.2	50.5	38	29.2	15.4	12.5
21:00:00	43.1	47.5	32.9	48.5	50.8	39.1	29.4	14.6	11.7
21:30:00	43.2	47.9	33.3	48.7	51.2	39.9	29.8	14.6	11.3
22:00:00	43.4	47.8	32.9	48.8	51.5	40.4	27.3	14.9	11.1
22:30:00	43.9	48.5	33.6	49	51.8	40.9	28.3	14.9	10.9
23:00:00	43.8	48.5	33.9	49	51.9	41.1	29	14.6	10.8
23:30:00	44.2	49	34.1	49.2	52.2	41.3	29	14.9	10.9
24:00:00	43.7	48.9	34	48.8	52.2	41.5	29	14.9	10.7
24:30:00	44.4	49.2	33.9	49.4	52.7	41.8	29.4	15.3	10.9
25:00:00	44.6	49.5	33.9	49.5	52.8	42	29.2	15.6	10.8
25:30:00	44	49.4	33.8	48.9	52.8	42.1	29.4	15.6	10.7
26:00:00	44.4	49.6	33.7	49.2	53	42.4	29.5	15.9	10.6
26:30:00	45.1	50.1	33.7	49.8	53.4	42.8	28.6	16.4	10.6
27:00:00	45.5	50.5	34.5	50.1	53.7	43.1	29	16	10.6
27:30:00	44.8	50.2	34	49.3	53.5	43.3	29.4	16.2	10.2
28:00:00	45.7	50.9	33.3	50.2	54	43.7	30	17.6	10.3
28:30:00	45	50.6	32.8	49.5	53.8	43.8	32.5	17.8	10
29:00:00	45.2	50.9	32.3	49.8	54	44.1	33.3	18.6	9.9
29:30:00	45.2	51	32.4	50	54.1	44.3	32.8	18.6	9.8
30:00:00	45.4	51.1	32.5	50.1	54.3	44.6	33.2	18.6	9.7
30:30:00	45.6	51.3	32.7	50.3	54.5	44.9	32.9	18.6	9.6
31:00:00	45.6	51.4	32.1	50.3	54.6	45.1	32.8	19.3	9.5
31:30:00	45.7	51.6	32.2	50.4	54.8	45.3	33	19.4	9.5
32:00:00	45.8	51.7	32.4	50.5	54.9	45.5	33.3	19.3	9.4
32:30:00	45.7	51.8	32.1	50.4	55	45.5	34	19.7	9.5
33:00:00	45.8	51.9	32.2	50.6	55.1	45.6	33	19.7	9.5
33:30:00	45.9	52.1	32.5	50.7	55.2	45.8	32.8	19.6	9.4
34:00:00	46	52.3	32.4	50.8	55.3	45.9	34.1	19.9	9.4
34:30:00	45.6	52.3	33.3	50.6	55.9	46.2	29.8	19	9.7
35:00:00	44.8	52.5	34.7	50.9	55.6	46.6	31.7	17.8	9
35:30:00	44.9	52.8	35	50.7	55.7	46.7	32.7	17.8	9
36:00:00	45.1	52.9	35.2	50.9	55.7	46.8	31.4	17.7	8.9
36:30:00	45.2	53	35.1	51.1	55.8	46.9	30.8	17.9	8.9
37:00:00	45.2	53.2	35.2	51.1	55.8	46.9	30.7	18	8.9
37:30:00	44.8	53.3	35.1	51.1	55.9	46.9	29.1	18.2	9
38:00:00	44.8	53.3	35.1	51.2	55.9	46.9	29.9	18.2	9
38:30:00	44.6	53.3	34.6	51.2	56	46.9	30.1	18.7	9.1
39:00:00	45.1	53.5	35.6	51	56.1	46.9	30.3	17.9	9.2
39:30:00	45.4	53.7	36.8	51.5	56.3	46.9	30.5	16.9	9.4
40:00:00	45.4	53.8	37	51.5	56.3	47	30.5	16.8	9.3
40:30:00	45.4	53.9	37.2	51.6	56.5	46.9	31	16.7	9.6
41:00:00	45.5	54	37.3	51.6	56.5	46.9	31.1	16.7	9.6
41:30:00	45.6	54.1	37.7	51.7	56.6	46.9	31.1	16.4	9.7

42:00:00	45.6	54.2	37.7	51.7	56.8	46.8	31	16.5	10
42:30:00	45.3	54.1	36.9	51.7	56.7	46.8	30.8	17.2	9.9
43:00:00	45.6	54.3	37.8	51.7	56.8	46.8	30.8	16.5	10
43:30:00	45.6	54.4	38.2	51.8	56.9	46.8	30.9	16.2	10.1
44:00:00	45.6	54.6	38.7	51.9	57.1	46.8	30.6	15.9	10.3
44:30:00	45.5	54.4	37.8	51.8	57.1	46.7	28.8	16.6	10.4
45:00:00	44.8	54.2	37.6	51.7	57	46.5	28.5	16.6	10.5
45:30:00	45.2	54.5	37.4	51.9	57.2	46.6	28.1	17.1	10.6
46:00:00	45.7	54.8	38.6	52.1	57.4	46.5	27.8	16.2	10.9
46:30:00	46	54.9	38.8	52.1	57.4	46.6	27.9	16.1	10.8
47:00:00	45.9	55.1	39	52.2	57.6	46.4	29.7	16.1	11.2
47:30:00	46	55.2	38.9	52.3	57.7	46.4	30.2	16.3	11.3
48:00:00	45.4	55	37.6	52.1	57.5	46.2	30.2	17.4	11.3
48:30:00	45.3	54.9	37	52.1	57.5	46.2	29.6	17.9	11.3
49:00:00	45.5	55.1	37.5	52.2	57.7	46.2	29.7	17.6	11.5
49:30:00	45.6	55.1	37.6	52.2	57.7	46.1	29.7	17.5	11.6
50:00:00	45.7	55.2	37.6	52.3	57.8	46	29.8	17.6	11.8
50:30:00	45.6	55.3	37.8	52.3	57.9	45.9	30.2	17.5	12
51:00:00	45.4	55.3	37.3	52.3	57.9	45.7	30.2	18	12.2
51:30:00	46.3	55.3	37.3	52.3	58	45.9	30.1	18	12.1
52:00:00	46.7	55.7	37.2	52.5	58.4	46	31	18.5	12.4
52:30:00	46.9	55.9	37.3	52.7	58.5	46	31.6	18.6	12.5
53:00:00	47.1	56	37.3	52.8	58.6	46.1	32.4	18.7	12.5
53:30:00	46.9	56	37.2	52.8	58.7	46	32.4	18.8	12.7
54:00:00	47.2	56.2	37.3	52.9	58.8	46.1	32.3	18.9	12.7
54:30:00	47.3	56.3	37.8	52.9	58.9	46.2	32.8	18.5	12.7
55:00:00	47.3	56.4	38.1	53	58.9	46.2	33.2	18.3	12.7
55:30:00	47.3	56.4	38.2	53	59	46.3	33.2	18.2	12.7
56:00:00	47.3	56.5	38.4	53	59.1	46.4	33.2	18.1	12.7
56:30:00	47.1	56	37.4	52.8	58.9	46.3	32.8	18.6	12.6
57:00:00	47.5	56.6	38.4	53.1	59.2	46.6	33	18.2	12.6
57:30:00	47.5	56.7	38.5	53.1	59.3	46.6	32.6	18.2	12.7
58:00:00	47.5	56.8	38.7	53.1	59.3	46.8	32.9	18.1	12.5
58:30:00	47.6	56.8	38.8	53.1	59.3	46.9	32.6	18	12.4
59:00:00	47.6	56.8	38.8	53.2	59.4	47	32.4	18	12.4
59:30:00	47.6	56.9	39	53.2	59.5	47	29.1	17.9	12.5
60:00:00	47.7	57	39	53.3	59.6	47.1	30	18	12.5
60:30:00	47.7	57.1	39.1	53.3	59.7	47.2	30.4	18	12.5
61:00:00	47.8	57.1	39.2	53.3	59.7	47.1	30.2	17.9	12.6
61:30:00	47.8	57.2	39.4	53.3	59.7	47.1	29.7	17.8	12.6
62:00:00	47.8	57.2	39.1	53.3	59.8	47.1	29.8	18.1	12.7
62:30:00	47.9	57.3	39.2	53.3	59.9	47.1	29.7	18.1	12.8
63:00:00	47.9	57.4	39.2	53.4	59.9	47.1	30.6	18.2	12.8
63:30:00	47.9	57.4	39	53.3	60	47	30.7	18.4	13
64:00:00	47.9	57.4	39.3	53.4	60.1	47.1	30.7	18.1	13
64:30:00	47.9	57.5	39.2	53.4	60.1	47.1	30.7	18.3	13
65:00:00	48	57.6	39.4	53.4	60.2	47.1	30.4	18.2	13.1
65:30:00	48	57.6	39.4	53.4	60.2	47.1	30.8	18.2	13.1
66:00:00	48	57.6	39.4	53.4	60.3	47.1	30.8	18.2	13.2
66:30:00	47.9	57.6	39.2	53.4	60.3	47	30.8	18.4	13.3

67:00:00	48.1	57.8	39.5	53.5	60.4	47.1	30.8	18.3	13.3
67:30:00	48.2	57.8	39.7	53.5	60.4	47.1	30.9	18.1	13.3
68:00:00	48.2	57.8	39.8	53.5	60.5	47.1	31	18	13.4
68:30:00	48.2	57.9	39.8	53.5	60.5	47	30.6	18.1	13.5
69:00:00	48.2	58	39.9	53.5	60.6	47	28.3	18.1	13.6
69:30:00	48.3	58	39.6	53.5	60.7	47	27.7	18.4	13.7
70:00:00	48.3	58.1	39.6	53.5	60.8	47	27.5	18.5	13.8
70:30:00	48.2	58	38.4	53.5	60.7	47	27.1	19.6	13.7
71:00:00	48.4	58.2	38.2	53.6	60.8	46.9	27.1	20	13.9
71:30:00	48.5	58.2	38.7	53.6	60.9	46.8	26.8	19.5	14.1
72:00:00	48.5	58.3	38.3	53.6	61	46.8	27	20	14.2
72:30:00	48.5	58.3	38.4	53.6	61	46.6	27	19.9	14.4
73:00:00	48.4	58.4	38.4	53.6	61	46.5	27.3	20	14.5
73:30:00	48.3	58.3	38	53.6	61	46.4	27.2	20.3	14.6
74:00:00	48.5	58.4	38.4	53.6	61.1	46.3	27.6	20	14.8
74:30:00	48.6	58.5	38.8	53.6	61.1	46.2	27.8	19.7	14.9
75:00:00	48.5	58.5	38.9	53.6	61.1	46.1	27.8	19.6	15
75:30:00	48.6	58.6	38.9	53.6	61.1	46	27.9	19.7	15.1
76:00:00	48.5	58.5	38.8	53.6	61.1	45.2	26.8	19.7	15.9
76:30:00	48.5	58.6	38.8	53.6	61.1	45.3	27.3	19.8	15.8
77:00:00	48.7	58.7	39.1	53.6	61.2	45.4	28.3	19.6	15.8
77:30:00	48.5	58.6	38.8	53.6	61.2	45.3	28.1	19.8	15.9
78:00:00	48.6	58.7	38.7	53.6	61.2	45.3	27.9	20	15.9
78:30:00	48.8	58.8	39.3	53.7	61.3	45.5	28.1	19.5	15.8
79:00:00	48.8	58.9	39.4	53.7	61.4	45.5	28.1	19.5	15.9
79:30:00	48.8	58.9	39.4	53.7	61.4	45.4	28	19.5	16
80:00:00	48.8	58.9	39.6	53.7	61.4	45.4	28	19.3	16
80:30:00	48.8	59	39.6	53.7	61.4	45.4	28	19.4	16
81:00:00	48.8	59	39.6	53.7	61.5	45.4	28	19.4	16.1
81:30:00	48.7	59	39.4	53.7	61.5	45.3	28.2	19.6	16.2
82:00:00	48.7	59	39.3	53.7	61.5	45.3	28.6	19.7	16.2
82:30:00	48.7	59	39.4	53.7	61.5	45.3	28.4	19.6	16.2
83:00:00	48.7	59	39.5	53.7	61.5	45.3	28.4	19.5	16.2
83:30:00	48.8	59.1	39.5	53.7	61.6	45.3	28.1	19.6	16.3
84:00:00	48.8	59.1	39.5	53.7	61.6	45.3	27.8	19.6	16.3
84:30:00	48.9	59.2	39.5	53.7	61.6	45.3	27.6	19.7	16.3
85:00:00	48.9	59.2	39.4	53.7	61.7	45.3	27.8	19.8	16.4
85:30:00	48.9	59.2	39.5	53.7	61.7	45.3	27.7	19.7	16.4
86:00:00	48.9	59.2	39.5	53.7	61.7	45.3	27.6	19.7	16.4
86:30:00	48.9	59.3	39.5	53.7	61.7	45.2	27.5	19.8	16.5
87:00:00	48.9	59.3	39.4	53.7	61.8	45.1	27.1	19.9	16.7
87:30:00	49	59.4	39.5	53.7	61.8	45.1	26.9	19.9	16.7
88:00:00	49.1	59.4	39.5	53.7	61.8	45.1	27	19.9	16.7
88:30:00	49.1	59.4	39.6	53.7	61.8	45.1	26.8	19.8	16.7
89:00:00	49.1	59.4	39.5	53.7	61.8	45.1	26.8	19.9	16.7
89:30:00	49.1	59.5	39.5	53.7	61.9	45	26.8	20	16.9
90:00:00	49.1	59.5	39.6	53.7	61.9	44.9	26.9	19.9	17
90:30:00	49.2	59.5	39.5	53.7	61.9	44.9	26.7	20	17
91:00:00	49.2	59.6	39.4	53.7	61.9	44.9	26.8	20.2	17
91:30:00	49.2	59.6	39.4	53.7	61.9	44.8	27.1	20.2	17.1

92:00:00	49.2	59.6	39.3	53.7	61.9	44.7	26.7	20.3	17.2
92:30:00	49.2	59.6	39.3	53.7	62	44.7	26.7	20.3	17.3
93:00:00	49.3	59.6	39.3	53.7	62	44.7	26.7	20.3	17.3
93:30:00	49.3	59.6	39.3	53.7	62	44.6	26.6	20.3	17.4
94:00:00	49.3	59.7	39.3	53.7	62	44.6	26.8	20.4	17.4
94:30:00	49.3	59.7	39.3	53.7	62	44.5	26.6	20.4	17.5
95:00:00	49.3	59.7	39.3	53.7	62	44.5	26.6	20.4	17.5
95:30:00	49.3	59.7	39.3	53.7	62	44.5	27	20.4	17.5
96:00:00	49.3	59.7	39.4	53.7	62	44.5	26.7	20.3	17.5
96:30:00	49.3	59.8	39.4	53.7	62	44.5	26.8	20.4	17.5
97:00:00	49.4	59.8	39.5	53.7	62.1	44.5	26.8	20.3	17.6
97:30:00	49.4	59.8	39.6	53.6	62.1	44.5	27.1	20.2	17.6
98:00:00	49.4	59.8	39.6	53.6	62.1	44.5	27.2	20.2	17.6
98:30:00	49.4	59.8	39.7	53.6	62.1	44.5	27.8	20.1	17.6
99:00:00	49.4	59.8	39.8	53.6	62.1	44.5	28.4	20	17.6
99:30:00	49.4	59.8	39.9	53.6	62.1	44.5	29.4	19.9	17.6
100:26:31	49.5	59.9	40.2	53.6	62.1	44.6	31.2	19.7	17.5
100:56:31	49.5	59.9	40.3	53.6	62.1	44.7	32.1	19.6	17.4
101:26:31	49.4	59.8	40.3	53.5	62	44.7	31.1	19.5	17.3
101:56:31	49.5	59.8	40.4	53.5	62.1	44.7	30.9	19.4	17.4
102:26:31	49.5	59.4	40.4	53.3	62	44.3	30	19	17.7
102:56:31	49.5	59.7	40.4	53.5	62	44.8	29.9	19.3	17.2
103:26:31	49.5	59.7	40.9	53.5	62	44.8	29.5	18.8	17.2
103:56:31	49.5	59.8	41.1	53.5	62	44.9	28.9	18.7	17.1
104:26:31	49.6	59.8	41.3	53.5	62.1	44.9	28.5	18.5	17.2
104:56:31	49.8	59.9	41.5	53.5	62.1	45	28.1	18.4	17.1
105:26:31	49.5	59.7	40.4	53.4	62	44.9	28.3	19.3	17.1
106:08:34	49.6	59.8	41.1	53.5	62	44.9	29.1	18.7	17.1
106:38:34	49.7	59.9	41.3	53.5	62.1	45	29.4	18.6	17.1
107:08:34	49.8	59.9	40.5	53.5	62.1	44.9	28.8	19.4	17.2
107:38:34	49.7	59.9	41.4	53.5	62.1	44.9	28.8	18.5	17.2
108:08:34	49.5	59.8	41.9	53.5	62.1	44.6	28	17.9	17.5
108:38:34	49.7	59.9	41.4	53.5	62.1	44.8	28	18.5	17.3
109:08:34	49.7	59.9	41.5	53.5	62.1	44.7	28	18.4	17.4
109:38:34	49.1	59.7	41.2	52.9	62.2	44.3	28.2	18.5	17.9
110:08:34	49.5	59.8	40.8	53.4	62	44.5	28.2	19	17.5
110:38:34	49.5	59.8	41	53.4	62	44.5	28.6	18.8	17.5
111:08:34	49.5	59.8	41.1	53.4	62	44.4	28.7	18.7	17.6
111:38:34	48.9	59.4	41.5	52.9	62.1	44	28.3	17.9	18.1
112:08:34	48.7	59.4	41.7	52.9	62.1	44	28	17.7	18.1
112:38:34	48.7	59.4	41.8	53	62.1	43.9	28	17.6	18.2
113:08:34	48.8	59.4	41.7	53	62.1	43.9	28.5	17.7	18.2
113:38:34	48.8	59.4	41.8	53	62.1	44	28.1	17.6	18.1
114:08:34	48.8	59.4	41.9	53	62	43.8	28	17.5	18.2
114:38:34	48.8	59.3	42	53	62	43.8	28	17.3	18.2
115:08:34	48.8	59.3	42.1	53	62	43.7	28	17.2	18.3
115:38:34	48.8	59.3	42.1	53	62	43.6	28	17.2	18.4
116:08:34	48.8	59.3	42	52.9	61.9	43.5	27.8	17.3	18.4
116:38:34	48.8	59.3	42.1	52.9	61.9	43.5	28	17.2	18.4
117:08:34	48.8	59.3	42.2	52.9	61.9	43.5	28	17.1	18.4

117:38:34	48.8	59.3	42.3	52.9	61.9	43.4	28	17	18.5
118:08:34	48.8	59.2	42.3	52.9	61.9	43.3	28.1	16.9	18.6
118:38:34	48.9	59.2	42.4	52.9	61.9	43.3	28	16.8	18.6
119:08:34	48.9	59.2	42.5	52.9	61.9	43.3	28.1	16.7	18.6
119:38:34	48.9	59.2	42.5	52.9	61.9	43.2	28.1	16.7	18.7
120:08:34	48.9	59.2	42.5	52.9	61.9	43.1	28	16.7	18.8
120:38:34	48.9	59.2	42.5	52.9	61.8	43.1	28.2	16.7	18.7
121:08:34	48.9	59.2	42.5	52.9	61.8	43	28.4	16.7	18.8
121:38:34	48.9	59.2	42.5	52.9	61.8	43	27.4	16.7	18.8
122:08:34	48.9	59.2	42.5	52.9	61.8	42.9	27.2	16.7	18.9
122:38:34	48.9	59.2	42.7	52.9	61.8	42.9	27.3	16.5	18.9
123:08:34	48.9	59.2	42.7	52.9	61.8	42.9	28	16.5	18.9
123:58:18	48.9	59.2	42.5	52.9	61.8	42.9	29.2	16.7	18.9
124:28:18	49	59.2	42.5	52.9	61.8	43	30.7	16.7	18.8
124:58:18	48.9	59.2	42.3	52.9	61.8	43	31.2	16.9	18.8
125:28:18	49	59.2	42.3	52.9	61.7	43.1	31.8	16.9	18.6
126:28:22	49.7	59.3	42	53.1	61.3	43.4	33.5	17.3	17.9
127:17:51	49.5	59.2	41.4	53	61.2	43.5	29.8	17.8	17.7
127:47:51	49.5	59.2	40.7	52.9	61.3	43.7	30.9	18.5	17.6
128:47:38	49.6	59.2	39.8	52.9	61.2	43.9	32	19.4	17.3
129:17:38	49.7	59.2	39.2	52.9	61.2	43.9	33.4	20	17.3
129:47:38	49.7	59.2	39.3	52.9	61.2	44.1	33.1	19.9	17.1
130:17:38	49.8	59.2	39.4	52.9	61.2	44.3	33.9	19.8	16.9
130:47:38	49.8	59.2	39.4	52.9	61.2	44.5	34	19.8	16.7
131:17:38	49.9	59.3	39.9	52.9	61.2	44.7	33	19.4	16.5
131:47:38	49.9	59.3	40	52.9	61.2	44.9	31.9	19.3	16.3
132:17:38	49.9	59.3	40.2	53	61.2	45.1	31.3	19.1	16.1
132:47:38	49.9	59.3	40.2	53	61.2	45.3	31	19.1	15.9
133:17:38	50	59.3	40.4	53	61.2	45.3	30.3	18.9	15.9
133:47:38	49.9	59.3	39.6	53	61.2	45.3	26.7	19.7	15.9
134:17:38	50	59.3	39.6	53	61.2	45.3	26.7	19.7	15.9
134:47:38	50	59.3	39.9	53	61.2	45.3	26.5	19.4	15.9
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136:47:38	50.1	59.3	40.2	53	61.1	45	28	19.1	16.1
137:17:38	50.1	59.2	40.1	53	61.1	44.9	28.1	19.1	16.2
137:47:38	50	59.2	40	53	61.1	44.9	27.9	19.2	16.2
138:17:38	50.1	59.2	40	53	61.1	44.8	28.2	19.2	16.3
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140:47:38	50.1	59.2	39.7	52.9	61	44.1	25.6	19.5	16.9
141:17:38	50.1	59.2	39.6	53	61	43.9	25.8	19.6	17.1
141:47:38	50.1	59.2	39.4	52.9	61	43.7	26	19.8	17.3
142:17:38	50.1	59.2	39.3	52.9	60.9	43.5	26.6	19.9	17.4
142:47:38	50.1	59.2	39.2	52.9	60.9	43.3	26.6	20	17.6
143:17:38	50.1	59.1	39.1	52.9	60.9	43.2	26.9	20	17.7
143:47:38	50.1	59.1	39.1	52.9	60.9	43.1	26.8	20	17.8

144:17:38	50.1	59.1	39	52.9	60.8	43.1	27	20.1	17.7
144:47:38	50.1	59	39	52.9	60.8	43	27	20	17.8
145:17:38	50.1	59	39	52.9	60.8	42.9	27.3	20	17.9
145:47:38	50.1	59	39	52.9	60.8	42.9	27.1	20	17.9
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147:47:38	50	59	38.9	52.8	60.7	42.8	28.3	20.1	17.9
148:17:38	50	58.9	38.9	52.8	60.6	42.8	29.4	20	17.8
148:47:38	50	58.9	38.9	52.8	60.6	42.8	28.1	20	17.8
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153:17:38	49.9	58.7	39.4	52.6	60.3	43.7	30.6	19.3	16.6
153:47:38	49.9	58.7	39.5	52.6	60.3	44	29.4	19.2	16.3
154:44:46	50	58.7	39.8	52.7	60.4	44.3	27	18.9	16.1
155:14:46	50	58.7	39.8	52.7	60.4	44.3	27.2	18.9	16.1
155:44:46	50	58.7	40	52.7	60.3	44.2	26.6	18.7	16.1
156:14:46	50	58.7	40.1	52.6	60.3	44.1	27.2	18.6	16.2
156:44:46	49.9	58.6	40.2	52.6	60.3	44	27.3	18.4	16.3
157:14:46	49.9	58.6	40.2	52.6	60.3	43.9	27.6	18.4	16.4
157:44:46	49.9	58.6	40.2	52.6	60.3	43.9	27.4	18.4	16.4
158:14:46	49.9	58.6	40.2	52.6	60.2	43.8	28	18.4	16.4
158:44:46	49.9	58.6	40.2	52.5	60.2	43.7	27.6	18.4	16.5
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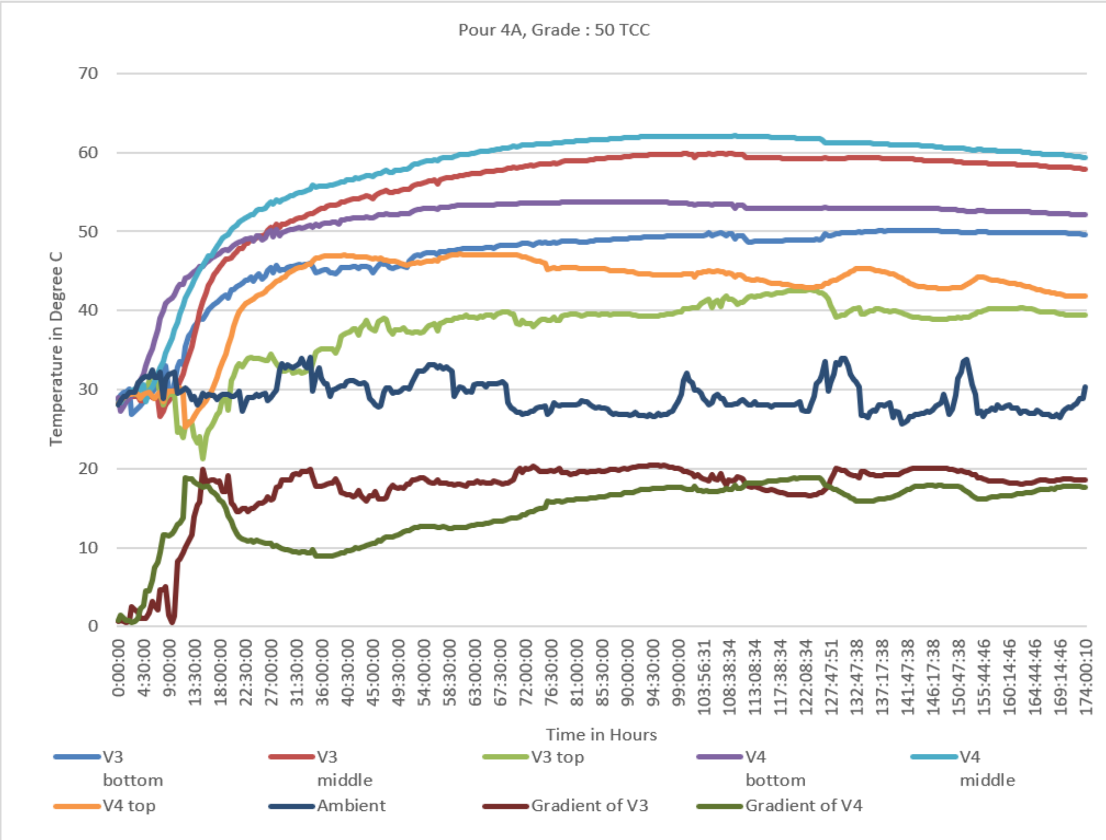
160:44:46	49.9	58.5	40.3	52.5	60.1	43.5	27.6	18.2	16.6
161:14:46	49.9	58.5	40.3	52.5	60.1	43.4	27.6	18.2	16.7
161:44:46	49.9	58.4	40.3	52.5	60.1	43.3	27.6	18.1	16.8
162:14:46	49.9	58.4	40.4	52.5	60.1	43.3	27	18	16.8
162:44:46	49.9	58.4	40.4	52.5	60	43.2	27.2	18	16.8
163:14:46	49.9	58.4	40.3	52.5	60	43.1	27.2	18.1	16.9
163:44:46	49.9	58.4	40.2	52.5	60	43	27	18.2	17
164:14:46	49.9	58.4	40.2	52.4	59.9	42.9	27	18.2	17
164:44:46	49.9	58.4	40.1	52.4	59.9	42.8	27	18.3	17.1
165:14:46	49.9	58.4	40	52.4	59.9	42.7	27.4	18.4	17.2
165:44:46	49.9	58.3	39.8	52.4	59.9	42.6	27.1	18.5	17.3
166:14:46	49.9	58.3	39.8	52.4	59.8	42.5	26.8	18.5	17.3
166:44:46	49.8	58.3	39.8	52.4	59.8	42.4	26.9	18.5	17.4
167:14:46	49.8	58.2	39.8	52.3	59.8	42.4	26.8	18.4	17.4
167:44:46	49.8	58.2	39.8	52.3	59.8	42.3	26.6	18.4	17.5
168:14:46	49.8	58.2	39.8	52.3	59.7	42.3	26.6	18.4	17.4
168:44:46	49.8	58.2	39.7	52.3	59.7	42.1	26.9	18.5	17.6
169:14:46	49.8	58.2	39.6	52.3	59.7	42.1	26.5	18.6	17.6

169:44:46	49.8	58.2	39.5	52.3	59.7	42	27.3	18.7	17.7
170:14:46	49.8	58.1	39.4	52.3	59.6	41.9	27.5	18.7	17.7
170:44:46	49.7	58.1	39.4	52.3	59.6	41.9	27.8	18.7	17.7
171:14:46	49.7	58.1	39.4	52.2	59.6	41.8	27.7	18.7	17.8
172:00:10	49.7	58	39.4	52.2	59.5	41.8	28.1	18.6	17.7
172:30:10	49.7	58	39.4	52.2	59.5	41.8	28.2	18.6	17.7
173:00:10	49.7	58	39.4	52.2	59.5	41.8	28.9	18.6	17.7
173:30:10	49.6	57.9	39.4	52.1	59.4	41.8	28.8	18.5	17.6
174:00:10	49.6	57.9	39.4	52.1	59.4	41.8	30.3	18.5	17.6

Graph-4.1



V.RESULT & DISCUSSION

The developed smart monitoring system was successfully implemented and tested on the selected structural model to evaluate its performance in monitoring key parameters such as temperature, and structural response. The system consisted of sensors, a microcontroller unit, which together enabled real-time data acquisition, transmission, and analysis. The results obtained from the system demonstrate its capability to continuously monitor the structural condition and provide meaningful insights into the behavior of the structure.

During the experimental phase, the temperature sensors installed on the structure recorded data accurately under varying environmental conditions. The sensors captured fluctuations in temperature, indicating changes that could influence material behavior. In particular, RTD PT100 sensors, when used in raft foundations, effectively monitor the heat generated during concrete hydration. This helps ensure that the temperature remains within safe limits, preventing thermal cracking. Due to their high accuracy and stability, these sensors provide reliable and continuous temperature data throughout the curing process, confirming that the system is sensitive and effective for temperature monitoring in structural applications.

The microcontroller unit functioned efficiently by collecting data from the sensors, which were connected to the data controller through wired communication, at regular intervals and converting it into digital form. The recorded data was then transferred using a pendrive for further analysis. The data was successfully displayed on the system in the form of graphs and charts, enabling easy interpretation of structural performance. This method of continuous monitoring reduces the need for frequent manual inspections and provides a more efficient and systematic approach to infrastructure management.

The monitoring of temperature using RTD Pt100 sensors in the raft foundation provided reliable and meaningful insights into the concrete hydration process. Temperature monitoring was initiated within 24 hours of casting and continued for a period of 7 days. The data indicated a rapid and nonlinear rise in temperature during the first 24–48 hours, with the temperature reaching its peak within 2–3 days, corresponding to the maximum heat generation during the exothermic hydration process.
The results also highlighted a significant thermal gradient within the raft, where the core recorded the highest temperature while the surface or periphery showed comparatively lower values. This variation is critical in assessing the risk of thermal cracking. In large raft foundations, peak temperatures recorded by PT100 sensors may exceed typical limits depending on the concrete mix design and thickness.

After reaching the peak, a gradual decline in temperature was observed, indicating the beginning of the cooling phase as the concrete started approaching ambient temperature. Although the complete cooling cycle generally extends up to 28 days, the 7-day monitoring period effectively captured the critical early-age temperature behavior.

The overall performance of the monitoring system was highly reliable, with RTD Pt100 sensors providing accurate and stable readings throughout the monitoring duration.

VI.CONCLUSION

6.1 The study demonstrates that RTD Pt100 sensors are highly effective for temperature monitoring in raft foundations during the concrete hydration process. The sensors provided accurate and consistent data, capturing the critical rise in temperature during the early stages and the subsequent cooling trend. The 7-day monitoring period was sufficient to observe peak temperature development and initial thermal behavior, which are crucial for assessing the risk of thermal cracking.

6.2 The results also highlighted the presence of thermal gradients between the core and surface of the raft, emphasizing the need for proper temperature control measures. With their high accuracy, stability, and durability, Pt100 sensors proved to be reliable even under harsh curing conditions.

6.3 Overall, the implementation of such monitoring systems enhances construction quality, supports better decision-making, reduces the need for manual inspection, and contributes to the long-term durability and safety of the structure.

VII.FUTURE SCOPE

The proposed smart monitoring system for sustainable infrastructure can be further enhanced in several ways to improve its efficiency, accuracy, and practical applicability. In future, the system can be implemented on large-scale real-world civil engineering structures such as bridges, high-rise buildings, dams, and highways. The use of high-precision and advanced sensors can improve the accuracy of data collection and provide more reliable results for structural analysis

Further development can include the integration of artificial intelligence and machine learning techniques for predictive maintenance. These technologies can analyze historical data and predict potential structural failures in advance, allowing engineers to take preventive measures. The system can also be expanded to monitor additional parameters such as humidity, displacement, crack detection, and corrosion, providing a more comprehensive assessment of structural health

In addition, the system can be powered using renewable energy sources such as solar panels to make it more sustainable and suitable for remote locations. Integration with smart city infrastructure and centralized monitoring systems can enable large-scale data management and decision-making. The development of mobile applications and advanced user interfaces can further improve accessibility and user experience. Overall, the future scope of this project lies in transforming it into a fully automated, intelligent, and scalable solution for smart and sustainable infrastructure management.

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