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Frequency Stability Analysis and Control of Multi-area Asynchronous Interconnected Systems: A Review

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Abstract: Concrete's versatility, strength, durability, and flexibility make it a popular building material. The major issue today is a lack of fresh water. For the combination and cure of concrete in production, drinkable water is necessary. It takes 28 days to complete the curing process. So there is a huge need for water in the construction industry for curing purposes. The Potable water is becoming less available every day for a number of reasons. Therefore, a substantial sum of cost must be spent on the purchase of water. Advanced technology must be utilized to water in a forbidden way in order to reduce the amount of water wasted throughout the healing process. A sensor is use to design the smart concrete curing system, which would automatically supply water for curing based on the amount of moisture present in the concrete and the ambient temperature and humidity. The compressive strength of concrete was predicting use a several functions based on the curing temperature, moisture content, and water level. The experiment investigation was performed to measure temperature, humidity, and compressive strength of 7, 28, and 42 days after fresh concrete was poured into the core and cube sample model. In this study, the average compressive strength calculated using the developed sensor in core and cube sample. Results finding the surface of slab floor relative humidity in concrete slabs with surface curing is measured in the laboratory as well as on site.

Keywords: Concrete curing, IOT, Smart Concrete, Compressive strength.

I. INTRODUCTION

Concrete is a construction material which is a viscous liquid mix of aggregate, cement and water at the beginning and needs a certain time period to get hardened and gain strength. (1) The process of hardening and gaining strength is an exothermic chemical reaction and known as “setting of concrete". The more sound setting process is the more quality concrete. So you should cure (look after) fresh concrete to ensure that its setting process continues in a healthy way. As mentioned above, setting is a chemical process and originates from cement and water that come in-contact each other. Cement starts hydration process and this produces heat. As the heat increases in fresh concrete it causes some of the water evaporate. As water evaporates there occurs an air void which is not good for concrete. And besides, as the water decreases the cement particles cannot gets enough water to be completely hydrated, thus making a sound setting impossible. So, the most important way of curing a concrete is to give water, to wash it just after it is hard enough to step over it without leaving any foot step. (2, 3)

The time periods needed can change according to the local conditions. But, since concrete is gains 50% of its max. Strength in 3 days, and 70% in 7 days these are critical days for water curing. Concrete continues to gain strength for years, but after 28 days it almost reaches 90% of its max expected strength so the water curing is no longer needed after 28 days. (4) Fresh concrete can also be protected against wind, very low temperatures, very high temperatures etc. All these precautions/actions (curing of concrete) are to ensure that the hydration of cement, thus the setting of concrete takes place in good condition. (5) Curing is the protection of fresh concrete from evaporation and temperature extremes which might adversely affect cement hydration. (6) If concrete is to gain potential strength and durability it must have sufficient water for the hydration of the cement, and a temperature conducive to maintaining this chemical reaction at a rapid, continuous rate. To ensure the existence of these conditions, the concrete must be protected from the harmful influences of wind, sun, and variable weather. As 23°C is considered the ideal temperature for hydration, it is desirable to maintain the concrete temperature at or about this figure as curing proceeds. (7, 8, 9) Concrete curing techniques fall into two groups - those designed to prevent loss of water, such as the application of impermeable membranes; and those that supply moisture throughout the early stages of the hydration process, such as ponding or the application of wet sand or hessian. Selecting the method of curing is generally a matter of economics, but another consideration is that the method used should cause the least interference to other operations on the site. (10) The curing process is crucial for the development of the concrete's strength and durability. It prevents the premature drying and cracking of the concrete surface, and ensures the cement paste fully hydrates and binds the concrete ingredients together. Proper curing can increase the final concrete strength by up to 50% compared to inadequate curing. It typically lasts for 7-28 days depending on the concrete mix, environmental conditions, and desired strength.

Concrete strength depends on the growth of crystal within the matrix of the concrete. (11) These crystals grow a reaction between Portland cement and water a reaction known as hydration. If there is not enough water, the crystal can't grow and the concrete doesn't develop the strength it should. If there is enough water, the crystals grow out like tiny rock hard finger wrapping round sand and gravel in the mix and intertwining with one another. (12) the other important aspect of curing is temperature the concrete cannot be too cold or too hot. as fresh concrete gets cooler, the hydration reaction slows down. The temperature of the concrete is what's important here, no necessary the air temperature. Below about 50F, hydration slows down a lot; below 40F it virtually slopes. Hot concrete has the opposite problem, the reaction goes too fast, and since the reaction is exothermic (produces heat), it can quickly cause temperature differential within the concrete that can lead to cracking and cement that reacts too quickly doesn't have time for the crystals to grow properly so it doesn't develop as much strength as it should. (13, 14)

The Internet of Things (IoT) is defined as the network of sensing and actuating devices that may communicate information across platforms using a single operating system to enable creative applications Furthermore, in the context of computer applications, it can be thought of as a network of sensors, actuators, or machines to enable real-time communications between various objects. (15) The IoT is an environment of things or objects that may communicate with one another and their neighbours through mobile phones, RFID tags, sensors, actuators, and other devices in order to accomplish predefined goals. Although the term "Internet of Things" has many definitions in the literature, a more comprehensive description is a "global network of interconnected objects uniquely addressable, based on standard communication protocols." Three distinct visions—i.e., things-oriented, internet-oriented, and semantic-oriented—converge to form the IoT notion. The integration of generic items into a common framework is embodied in the things oriented vision. This viewpoint allows for the evaluation of IoT as a tool for network connectivity, autonomous data collection, event transfer, and interoperability.

Sensors Used

The proposed IoT-based device parameters, concrete temperature, moisture content, air temperature, humidity, and wind speed, are considered in this research. To monitor those factors, the proposed IoT based device is composed of 3 sensors, 1 programmable microcontroller, and 1 water pump. The working principle into maintain the required moisture content by spraying water on the concrete surface at defined time intervals, so as to automatically maintain concrete surface dampness and temperature. (16, 17, 18) Temperature and Humidity Sensor (DHT11) used a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (no analog input pins needed). It's fairly simple to use but requires careful timing to grab data. Waterproof Temperature Sensor (DS18B20) uses (19) The DS18B20 temperature sensor is a waterproof temperature sensor module that can be used to measure the temperature underwater. It uses a 1-wire interface for communication with the microcontroller. DS18B20 is very precise and it works in the range of -55 degrees to 125 degrees Celsius with an Accuracy of ±0.5°C. It can be powered with 3V to 5.5V power supply and it only consumes 1 mA of current during its working. Here is a list of the specifications for the DS18B20. Water Pump (5v DC Mini Water Pump) for curing of IoT. a pump that operates on 3-6 V and gives an output of above 70 L/H then this could be the best choice for our project. This DC 3-6 V Mini Micro Submersible Water Pump is a low-cost, small-size Submersible Pump Motor that can be operated from a 2.5 ~ 6V power supply. It can take up to 120 liters per hour with a very low current consumption of 220mA. Just connect the tube pipe to the motor outlet, submerge it in water, and power it. A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip. They are also used in consumer electronics products, such as gaming systems, digital cameras, and audio players. (20, 21, 22, 23)

II. EXPERIMENTAL PERFORMANCE

M20-grade concrete is used for laboratory experiments, and 1mx1mx1m slab surface and concrete core extracted through slab model were produced. The various tests would be conducted for designed concrete mixes, thereby studying the smart concrete on various properties such as slump cone test, compressive strength, and wet sieve analysis (IS 1727). Age of concrete is considered is 7, days, 42days, 28 days.

The experimental performance done in 28 days curing for slab surface by IoT device for the core sample and cube sample is measured humidity, temperature, and water level results are calculated in sensors.

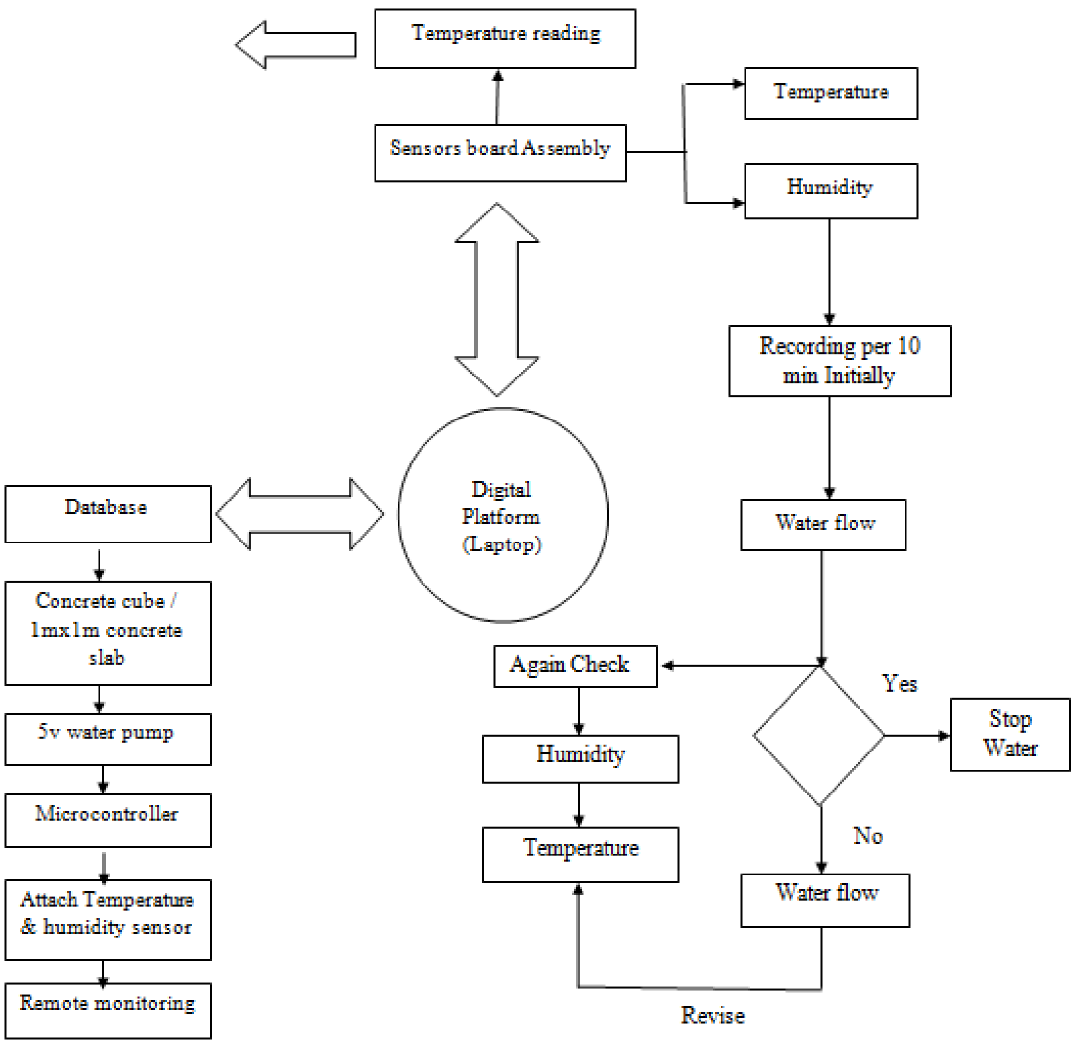


Figure 1: Flowchart of Experimental Work

2.1. Experimental Setup

- **Casting of Specimen**

Three cubes of concrete, each measuring 0.15 m by 0.15 m by 0.15 m, were cast using a mix ratio of M20 grade concrete. The mix for concrete had a weight ratio of 0.5: 1: 1.5: 3 for water cement, sand, and aggregate. The cube specimen was evaluated after seven, fourteen, twenty-eight, and forty-two days of curing. For the purpose of to determine the specimen's compressive strength, a compression testing machine was used.

For the purpose of to prevent any cavities, this concrete is thoroughly tempered after being put into the mould. Moulds are taken out after a day, and test specimens are cured in water. This specimen ought to possess a smooth, level top surface. This is accomplished by applying cement paste and smoothing it over the entire specimen. After seven or twenty-eight days of curing, these specimens are sent through a compression testing equipment. Until the specimen fails, the load should be applied gradually at a rate of 140 kg/cm2 per minute. Concrete's compressible strength is calculated by dividing the load at failure by the specimen's area. (24)

Table 1: Materials of the Sample Mixture

Materials	**Types**
Type of cement	OPC 53 Grade Confirming IS12269
Concrete	M20 – concrete,
Aggregate	20 mm
W/C ratio	0.52 (Table 5 of IS 456:2000)
Exposure Condition	Mild

Table 2: Mix Proportions (As Per Is 10262-2009)

Sample	By weight (kg/m3)	By Weight (Kg)
Cement	368	50
Fine aggregate	768.28	104.27
Coarse aggregate	1162.69	157.8
Water	191.58	26 (Litre)

- **Mixing of Concrete for Cube test**

Mix the concrete either by hand or in a laboratory batch mixer

1. Mix the cement and fine aggregate on a watertight none-absorbent platform until the mixture is thoroughly blended and is of uniform color.
2. Add the coarse aggregate and mix with cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch.
3. Add water and mix it until the concrete appears to be homogeneous and of the desired consistency.

Figure No 1 Hand Mixing

- **Curing**

Submerge each concrete specimen in a water tank to cure it. The test specimens are marked, pulled out of the moulds, and maintained submerged in clear freshwater until they are retrieved before the test. They are then stored in moist air for a full day.

Figure No 2 Curing Of Samples

In a laboratory setting, IoT-enabled curing was conducted on a concrete slab measuring 1 m x 1 m x 1 m, showcasing a modern approach to optimizing the curing process. This IoT system comprises various components, including temperature and moisture sensors that continuously monitor the concrete's internal conditions, ensuring optimal hydration. An automated spraying system is integrated to deliver water precisely when moisture levels drop below a predetermined threshold, preventing issues like cracking and ensuring proper curing. Data from these sensors is transmitted to a cloud-based platform via a gateway, allowing for real-time analysis and remote monitoring through a user-friendly dashboard or mobile application. The system's ability to maintain ideal temperature and moisture levels not only enhances the quality and durability of the concrete but also reduces the need for manual intervention, streamlining the curing process. By automating these critical parameters, the IoT-enabled curing process promotes sustainable practices through efficient resource use, enabling predictive analytics for future construction projects. Ultimately, this integration of IoT technology represents a significant advancement in concrete curing, leading to more resilient structures and improved overall efficiency in the construction industry.

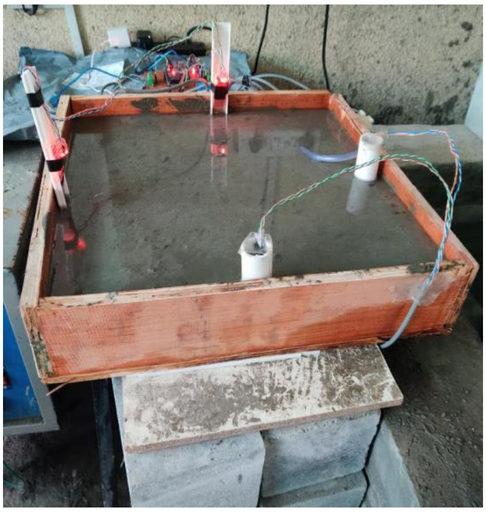


Figure No 3 **IoT Device Curing**

- **Relative Humidity test**

For this procedure, a humidity probe must be put 40 percent of the way below the concrete after holes have been drilled into it. The measurement in the center of the slab and the quantitative result make this test a more precise and trustworthy method of measuring MVT. (25)

Figure No 4 **Drilled Concrete Hole**

After drilling, the hole is filled with an in-situ probe. This probe gives a RH reading based on a percentage and measures the humidity deep within the slab. The percentage shows the relative moisture content of the air inside the concrete to the maximum moisture content that the air might contain at the same temperature. Concrete moisture can be tested most accurately using the in-situ relative humidity (RH) testing method. It offers a precise assessment of the slab's ultimate moisture status in the event that a flooring product were applied at that time. The most precise method for evaluating concrete moisture is the ASTM F2170 standard, which outlines the RH testing procedure. This standard is acknowledged by flooring and adhesive manufacturers. By inserting RH sensors into the concrete slab, this technique gives an accurate assessment of the amount of moisture present.

We utilised the Node MCU, a microcontroller, as a temperature sensor interface. The Arduino open source coding software also transmits the written program to this microcontroller. Code uses a specific formula to determine the temperature and transforms the unknown result into an intelligible one. Additionally, the micro-controller can only access the cloud for monitoring purposes with the aid of code. The temperature sensor detecting module is circuited utilising the micro-controller (Node MCU). After applying a 5 volt supply to one of the sensor module's three leads and grounding the other lead, data about the surrounding environment is gathered, validated using a coded algorithm, and then transferred to the cloud monitoring process. (26)

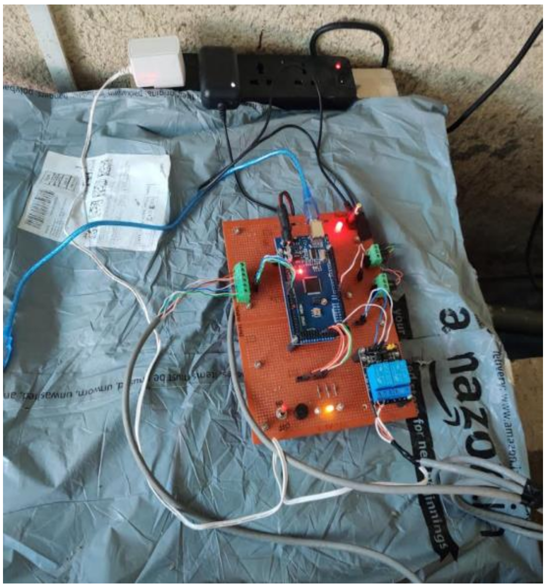


Figure No 5 Circuit Setup

Figure No 6 **Specimen with Sensors**

The Universal Testing Machine (UTM) is a dual-testing device that is capable of both tensile and compression testing. An overview of all the properties of concrete can be obtained from the concrete cube test's compressive strength. This one test allows one to determine whether or not concrete has been done correctly.Either a cube or a cylinder is used for the compressive strength test. A concrete cylinder or cube is suggested as the standard specimen for the test by a number of standard codes. The Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens is provided by the American Society for Testing Materials (ASTM) C39/C39M..

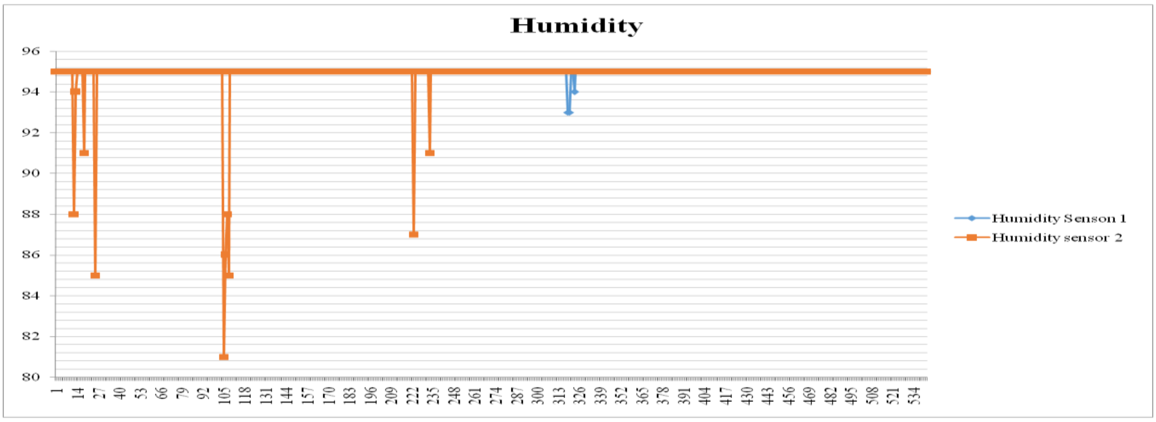
Figure No 7 **Sample Testing In Laboratory**

III. RESULT AND DISCUSSION

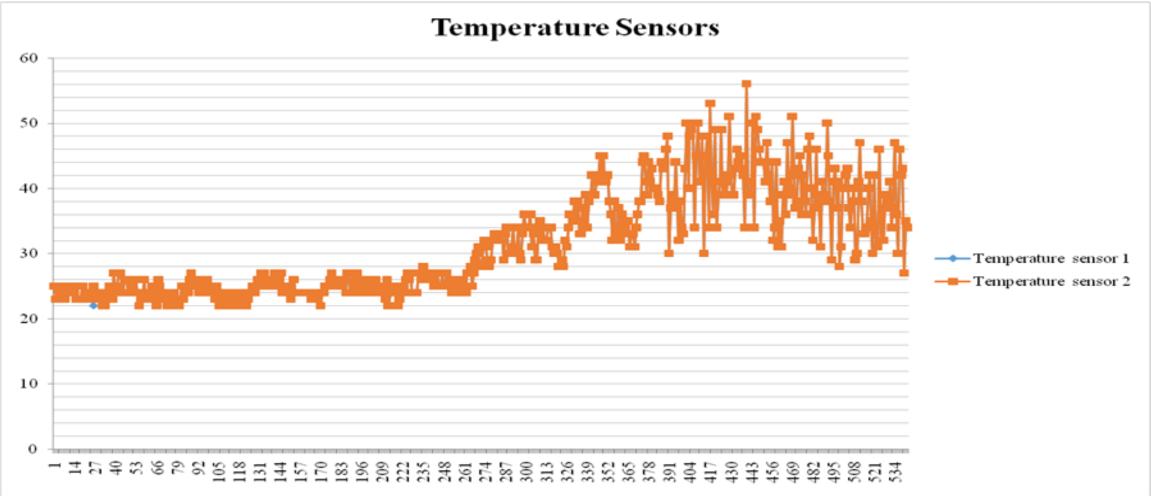
3.1. Real Time Data Analysis

Every message is analysed as it is received by real-time analytics, which process data fed through a feed. Geofencing, event detection, and data transformation are three specific applications of real-time analytics. The Internet of Things gadget saves time and work by allowing data collection and concrete curing processes to happen automatically. The devices can be used to monitor concrete temperature, moisture content, wind speed, air temperature, and humidity by combining and adopting three sensors. All collected sensor data in IOT devices are displayed on a connected computer for real-time monitoring and decision-making. The IoT platform can be used to further share the data via remote connections. (27)

The sensor transmits data to the Wi-Fi microcontroller in real time, recording the concrete's internal temperature. The C programming language is utilized to create a program that is input into the microcontroller, which uses the developed strength vs maturity relationship for the relevant concrete mix to determine the early age compressive strength. The ESP8266 microcontroller is programmed in C using the Arduino Integrated Development Environment (IDE). The following fields were added to a new Thingspeak.com channel: compressive strength, temperature, and maturity index. The C program that is put into the ESP8266 microcontroller should contain the Wi-Fi login credentials and the Thing Speak channel address. The ESP8266 microcontroller displays the data in the Organic Light-Emitting Diode (OLED) display and sends them to the cloud platform in real time, which can be accessed from any remote location. A maturity meter is available in the market, which is a conventional tool for the manual recording of the compressive strength of concrete at the site by measuring the internal temperature. Because this instrument is operated manually, frequent recording of the internal temperature is cumbersome for the real time prediction of compressive strength. In addition, a software program is generally required by the conventional maturity meter to extract and analyze the data on a computer. These drawbacks are rectified in the proposed system to enable automation in the recording of the internal temperature and the computation of maturity indices. The use of a data logger in a conventional maturity meter is replaced with cloud connectivity and, thus, the chance of any data loss is eliminated. The cloud connectivity available with the proposed IoT based system enables real time monitoring from any remote location that is not available with a conventional maturity meter.(28)



Graph No1: Humidity Sensors



Graph No 2: Temperature Sensors

Humidity

Table No 1: Humidity Results

Day	Humidity Sensors 1		Humidity Sensors 2	
	Average Humidity Per Day	% Variation	Average Humidity Per Day	% Variation
Day 1	95	0.01	94.4	0.48
Day 2	95	0.01	94.5	0.38
Day 3	95	0.01	95	0.15
Day 4	95	0.01	95	0.15
Day 5	95	0.01	95	0.15
Day 6	95	0.01	93	1.96
Day 7	95	0.01	95	0.15
Day 8	95	0.01	95	0.15
Day 9	95	0.01	95	0.15
Day 10	95	0.01	95	0.15
Day 11	95	0.01	95	0.15
Day 12	95	0.01	94.4	0.48
Day 13	95	0.01	95	0.15
Day 14	95	0.01	95	0.15
Day 15	95	0.01	95	0.15
Day 16	94.8	0.20	95	0.15
Day 17	94.95	0.04	95	0.15
Day 18	95	0.01	95	0.15
Day 19	95	0.01	95	0.15
Day 20	95	0.01	95	0.15
Day 21	95	0.01	95	0.15
Day 22	95	0.01	95	0.15
Day 23	95	0.01	95	0.15
Day 24	95	0.01	95	0.15
Day 25	95	0.01	95	0.15
Day 26	95	0.01	95	0.15
Day 27	95	0.01	95	0.15

The IoT device measures concrete slab humidity sensors reading in 28 days in each 20 reading. The two sensor readings are measure; in humidity sensors, the average humidity per day is 95, and the total 28-day average humidity is 94.99. Result concludes percentage variation is 0.01 Humidity 1 reading are similar to each other. In humidity sensors 2 the average humidity per day is 94.5, and for total 28 days, the average humidity is 94.86. The percentage variation is observed. 0.15, 0.38, 0.48, 1.96

Table No 2: Compressive Strength

Sample	Testing Days	Compressive Strength	Average Compressive Strength	Difference In Strength Of Cube And Core	% Difference
Core	28	22.23	21.40	1.34	5.91
		20.58			
Cube	28	22.56	22.75		
		22.1			
		23.58			

Table illustrates the compressive strength measure core and cube for 28 days. The average compressive strength of core is 21.40KN/mm2 and cube for 22.75 KN/mm2. Result observed the cube and core strength difference is 1.34. Finally 5.91 percentage difference are found which is below 10% it's remarkable for good in curing for concrete.

Temperature

Table No 3: Temperature Result

Day	Temperature Sensor1		Temperature Sensor2	
	Average Temperature Per Day	% Variation	Average Temperature Per Day	%Variation
Day 1	23.9	23.35	23.95	23.22
Day 2	23.55	24.47	23.75	23.86
Day 3	24.55	21.26	24.55	21.3
Day 4	23.4	24.95	23.4	24.98
Day 5	24.85	20.3	24.85	20.33
Day 6	23.25	25.43	23.25	25.47
Day 7	24.9	20.14	24.9	20.17
Day 8	24.7	20.78	24.7	20.81
Day 9	24.3	22.07	24.3	22.1
Day 10	25.35	18.7	25.35	18.73
Day 11	24.35	21.91	24.35	21.94
Day 12	25.85	17.09	25.85	17.13
Day 13	25.5	18.22	25.5	18.25
Day 14	28.7	7.95	28.7	7.99
Day 15	32	2.63	32	2.6
Day 16	32.45	4.07	32.45	4.04
Day 17	33.85	8.56	33.85	8.53
Day 18	38.8	24.44	38.8	24.41
Day 19	37.2	19.31	37.2	19.28
Day 20	39.2	25.72	39.2	25.69
Day 21	43.8	40.47	43.8	40.44
Day 22	42.4	35.98	42.4	35.95
Day 23	41.7	33.74	41.7	33.71
Day 24	40.5	29.89	40.5	29.86
Day 25	38.2	22.51	38.2	22.48
Day 26	37.3	19.63	37.3	19.6
Day 27	37.4	19.95	37.4	19.92

The internet of things device is measures concrete slab temperature sensors reading in 28 days in each 20 reading. The two sensor readings are measure; in temperature sensors, the maximum average temperature per day is 43.8, average temperature is varied in 23 to 43. and the total 28-day average temperature is 31.18. Result concludes percentage variation is 40.43 temperatures 1 reading are slightly different. In temperature sensors 2 the average temperature per day is 43.8, and for total 28 days, the average humidity is 31.19. The percentage variation is observed. 40.44

Table No 4: Final Results

Description	Initial Reading	Average Reading Per Day	% Variation
Humidity 1	95	95	0.01
Humidity 2	95	94.4	1.96
Temperature 1	56	43.8	40.47
Temperature 2	56	43.8	40.44
Core compressive strength	22.23	21.4	5.91
Cube compressive strength	23.58	22.75	5.91

IV. CONCLUSION

IoT devices will enable more accurate and efficient concrete curing. the proposed Internet of Things device under study monitors the weather and the amount of water lost by the curing concrete in real time. Since the amount of replacement water sprinkled on the concrete surface is governed by ambient environmental conditions, this will prevent an excessive water load input into the already hydrated and vulnerably weak cement paste matrix. The volume of water utilized during the operation and the condition of the surroundings can be automatically recorded for further analysis. Data will be sent to a computer platform for intercommunication without the requirement for human intervention. Because of this, the head office can effectively collect data through the computer platform, and decision-makers are only alerted when there is a change or anomaly in the amount of water required by the curing concrete. The enormous amounts of water and labour needed for the conventional manual-based curing process are eliminated by this equipment. As a result, Internet of Things (IoT) is a new technology that might be applied in the construction sector to address a number of problems related to construction management. The construction business may gain favorable effects from IoT application methods by implementing the technology. The Internet of Things system can be integrated with several apps that are now being used in the building industry. To enhance the functionality of smart or intelligent buildings, smart items, health and safety measures, monitoring systems, quality control, etc., further research can be done in the future. (29, 30)

IoT is a novel technology and has a potential to be used in the construction industry to improve several issues under the construction management topic. By applying the IoT technology, the construction industry may benefit from its application practices in a positive manner. The system of IoT can be integrated with different applications which are already in use in construction. For future studies, additional research efforts can be carried out in order to improve the performance of smart or intelligent building, smart objects, health and safety precautions, monitoring systems, quality control, etc.

The experimental results conclude average compressive strength per day of core and cube sample is 21.40N/mm2 and 22.75 N/mm2. The average reading of humidity 1 and humidity 2 is 95 and 94.4. Similarly, the average reading per day of temperature 1 and temperature 2 is 43.8, 43.8 degree Celsius

In humidity 1 & 2 results percentage variation of initial and average reading per day is 0.01, 1.96 In temperature 1 & 2 results percentage variation of initial and average reading per day is 40.47, 0.44. In cube and core compressive strength results of percentage variation of initial and average reading per day is 5.91

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