Real Time Deformation Monitoring in Structures Using IoT

Dr.Jegatheeswaran B[1], Gokulnath N[2], Sivanraj S[3], KarthikaG[4], Keerthana S[5]
[1]*Assistant Professor, Department of Civil Engineering, AAA College of Engineering and Technology, Sivakasi 626 005, Tamil Nadu, India*
[2,3,4,5] *UG Student, Department of Civil Engineering, AAA College of Engineering and Technology, Sivakasi 626 005, Tamil Nadu, India*

***Abstract*—Dams are vital infrastructures that play a major role in water storage, power generation, and flood control. However, continuous exposure to hydrostatic pressure, temperature variations, and material aging can lead to internal deformation or pressure imbalances, potentially causing structural damage or failure. Traditional monitoring methods depend on manual inspections and periodic measurements, which are time-consuming, less accurate, and incapable of providing real-time alerts during emergencies. This project proposes an IoT-based real-time dam monitoring system that continuously measures deformation and internal water pressure using multiple flex (flex) sensors interfaced with a NodeMCU ESP8266 (CP2102) microcontroller. The sensor data is transmitted to the ThingSpeak IoT Cloud for continuous monitoring, visualization, and storage. When any abnormal deformation or pressure value is detected, the system automatically triggers a buzzer and email alert, ensuring early warning and timely preventive action.**

***Index Terms*—NodeMCU ESP8266, Thinspeak, Email alert, Early Warning**

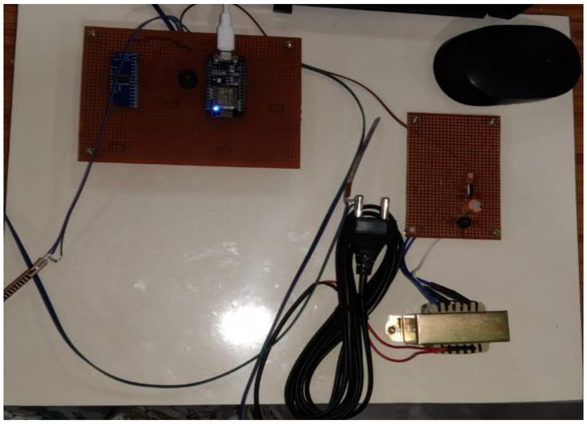
I. INTRODUCTION

Dams are among the most critical infrastructures in civil engineering, designed to store and regulate water for irrigation, power generation, and flood control. However, due to continuous exposure to hydrostatic pressure, temperature variations, and material aging, dams are susceptible to internal deformation, seepage, and stress accumulation. Continuous monitoring of these parameters is essential to ensure the safety, stability, and longevity of the structure. Traditional dam monitoring methods rely heavily on manual inspections and mechanical instruments, which often fail to provide real-time data or early warning signals in case of abnormal pressure build-up or structural deformation. Such limitations can lead to delayed detection of potential failures, posing serious risks to both the infrastructure and nearby communities.

To address these challenges, this project proposes an IoT-based real-time deformation and pressure monitoring system using Flux Sensor 2 and a Pressure Sensor integrated with a NodeMCU ESP8266 (CP2102) microcontroller. The system continuously measures water pressure and structural deformation values and transmits the data to the Thingspeak IO Cloud for live monitoring and 24-hour data tracking. Whenever the readings exceed a predefined safety limit, an automatic email alert is generated to notify the concerned authority, allowing timely preventive action. This system provides a cost-effective, scalable, and smart monitoring solution that enhances dam safety management through early fault detection and predictive maintenance. Moreover, the project demonstrates the application of IoT technology in civil engineering, bridging the gap between structural health monitoring and intelligent data-driven decision-making.

II. LITERATURE REVIEW

Structural health monitoring of large civil infrastructures such as dams has gained significant attention in recent years due to increasing safety concerns and aging structures. Traditional monitoring methods mainly depend on manual inspection, mechanical instruments, and periodic data collection, which are often time-consuming, labor-intensive, and incapable of providing real-time alerts during critical conditions. To overcome these limitations, researchers have increasingly adopted IoT-based monitoring systems for continuous and remote observation of structural parameters.



Sharma et al. proposed an IoT-based real-time structural health monitoring system for dam structures using wireless sensors and cloud connectivity. Their system demonstrated the effectiveness of IoT technology in collecting real-time deformation data and improving decision-making for dam safety. However, the study focused mainly on data acquisition and lacked an automated alert mechanism for emergency situations.

Patil and Kulkarni developed a wireless sensor network-based monitoring system for dam safety using IoT concepts. The system enabled remote monitoring of structural parameters and reduced dependency on manual inspection. Although the system improved monitoring efficiency, issues related to sensor calibration and long-term reliability were identified as major challenges.

Rahman et al. presented an IoT-based water pressure monitoring system for hydraulic structures. The study highlighted the importance of real-time pressure monitoring in preventing structural failures caused by excessive hydrostatic forces. While effective in pressure measurement, the system did not integrate deformation sensors, limiting its ability to provide a complete structural health assessment.

Gupta and Singh investigated the application of flux sensors for measuring deformation and strain in civil engineering structures. Their research confirmed that flux sensors are capable of detecting minute structural movements with high sensitivity. However, the implementation was limited to laboratory-scale experiments and did not include cloud-based data visualization or real-time alerts.

Hossain et al. designed a real-time IoT monitoring system for dam structures using an ESP8266 microcontroller. The system successfully transmitted sensor data to a cloud platform for continuous monitoring. Despite its advantages, the study relied on rule-based monitoring and lacked predictive or multi-sensor integration for comprehensive dam safety evaluation.

Recent studies have also emphasized the use of cloud platforms such as ThingSpeak and Adafruit IO for real-time data visualization and storage. These platforms provide user-friendly dashboards and support automated alert mechanisms using services like email or SMS. However, many existing systems still depend on single-sensor configurations and do not fully exploit multi-sensor integration for reliable deformation and pressure monitoring.

From the literature, it is evident that IoT-based monitoring systems offer a cost-effective and efficient solution for structural health monitoring of dams. Nevertheless, gaps remain in the integration of multiple sensors, real-time alert mechanisms, and continuous 24×7 monitoring systems specifically designed for dam deformation and pressure analysis.

III. PLANNING AND ARCHITECTURE

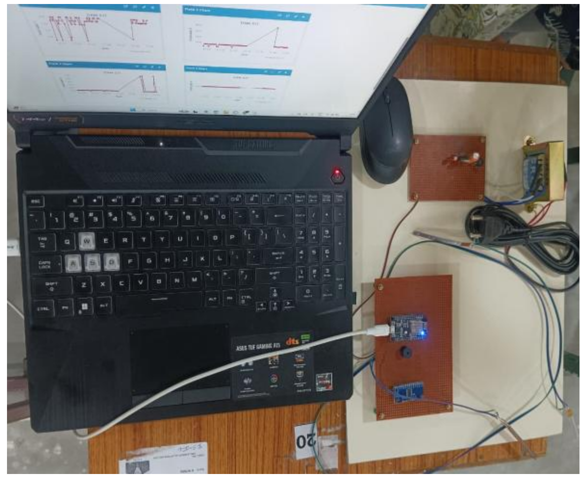
The planning of the proposed IoT-based dam monitoring system focuses on developing a reliable, continuous, and real-time solution for detecting deformation and internal water pressure in dam structures. The primary objective of the system planning is to ensure early identification of abnormal structural behavior while minimizing manual inspection and human intervention. During the planning phase, critical locations on the dam body are identified for sensor placement based on stress concentration zones and water pressure distribution areas.The system is designed to operate continuously under environmental conditions such as humidity, temperature variations, and long-term exposure to water. Low-cost and energy-efficient components are selected to ensure scalability and ease of deployment.

The monitoring system is planned to provide real-time data acquisition, wireless data transmission, cloud-based storage, and automated alert generation to enhance dam safety management. Threshold values for deformation and pressure are predefined based on safe operating limits of the dam. When sensor readings exceed these thresholds, the system immediately triggers alerts to enable timely preventive actions. The planning also emphasizes future extensibility, allowing additional sensors or advanced data analytics to be integrated without major hardware modifications

IV. MATERIALS AND SOFTWARE USED

The proposed IoT-based dam deformation and pressure monitoring system consists of a combination of hardware components and software tools that work together to achieve continuous real-time monitoring and alert generation. The core hardware component of the system is the NodeMCU ESP8266 (CP2102) microcontroller, which acts as the central processing and communication unit. It is responsible for acquiring analog signals from the connected sensors, converting them into digital values, processing the data, and transmitting it wirelessly to the cloud platform using its built-in Wi-Fi module. The CP2102 USB-to-UART interface allows easy programming and reliable serial communication, making the microcontroller suitable for long-term monitoring applications with low power consumption.

Flux (flex) sensors are used to measure structural deformation in the dam. These sensors operate based on changes in electrical resistance when subjected to bending or mechanical stress. When deformation occurs in the dam structure, the resistance of the flux sensor varies, producing a corresponding voltage change. This voltage variation is measured by the NodeMCU through a voltage divider circuit, enabling accurate detection of small structural movements and early signs of cracks or stress concentration. In addition to deformation monitoring, a pressure sensor is employed to measure internal water pressure acting on the dam structure. The pressure sensor converts the applied hydrostatic force into an electrical signal, allowing continuous monitoring of pressure variations that may lead to structural instability if left undetected.



To support multiple sensor connections, a CD74HC4067 analog multiplexer is used in the system. The multiplexer enables several flux and pressure sensors to be connected to a single analog input pin of the NodeMCU, reducing wiring complexity and improving system scalability. A buzzer is integrated into the system to provide immediate local alerts when sensor readings exceed predefined safety threshold values. This ensures that on-site personnel receive instant warning during abnormal conditions. The circuit is assembled using a breadboard and jumper wires, which provide flexibility for testing and debugging without the need for permanent soldering. A regulated 5V DC power supply or USB power source is used to ensure stable and continuous operation of the system.

The software component of the system includes the Arduino Integrated Development Environment (IDE), which is used to write, compile, and upload the control program to the NodeMCU ESP8266. The Arduino IDE facilitates sensor data acquisition, threshold comparison, Wi-Fi connectivity, and cloud data transmission. For data storage and visualization, the ThingSpeak IoT cloud platform is utilized. The sensor data transmitted from the NodeMCU is stored in ThingSpeak channels and displayed in real time using graphical plots and dashboards. The platform also supports automated alert services through integration with IFTTT, enabling email notifications to be sent whenever sensor readings exceed safe limits. Together, these hardware and software components form a reliable, cost-effective, and scalable system for real-time dam structural health monitoring.

V. METHODOLOGIES

The methodology adopted in this work focuses on the design and implementation of an IoT-based real-time monitoring system for measuring deformation and internal water pressure in dam structures. The overall approach involves sensor installation, data acquisition, signal processing, wireless data transmission, cloud-based monitoring, and automated alert generation. The system is designed to operate continuously to ensure early detection of abnormal structural behavior and improve dam safety management.

In the first stage, multiple flux (flex) sensors and pressure sensors are installed at critical locations on the dam structure where deformation and pressure variations are most likely to occur. These locations are selected based on structural stress zones and water pressure distribution. The sensors continuously respond to physical changes in the structure by producing corresponding analog electrical signals. Voltage divider circuits are used to convert resistance variations of the flux sensors into measurable voltage levels suitable for microcontroller input.

In the data acquisition stage, the analog sensor signals are routed through a CD74HC4067 multiplexer to the NodeMCU ESP8266 microcontroller. The multiplexer allows multiple sensors to share a single analog input pin, improving scalability and reducing hardware complexity. The NodeMCU periodically reads the sensor values, converts them into digital form using its internal analog-to-digital converter, and performs basic signal processing to remove noise and ensure stable readings.

The processed sensor data is then compared with predefined threshold values that represent safe operating limits of the dam. These thresholds are determined based on structural safety considerations and expected operational conditions. When the measured values remain within safe limits, the system continues normal monitoring and data logging. If any sensor reading exceeds the threshold value, the system identifies the condition as abnormal and initiates an alert response.

For communication, the NodeMCU uses its built-in Wi-Fi capability to transmit the processed data to the ThingSpeak IoT cloud platform at regular intervals. The data is sent using standard HTTP or MQTT protocols, ensuring reliable and secure wireless communication. The cloud platform stores both real-time and historical data, enabling continuous monitoring, trend analysis, and visualization through graphs and dashboards.

An automated alert mechanism is integrated into the system to ensure immediate response during critical situations. When abnormal deformation or pressure values are detected, a buzzer is activated to provide local on-site alerts. Simultaneously, ThingSpeak services integrated with IFTTT trigger email notifications to inform responsible authorities and maintenance personnel. This dual alert mechanism ensures timely preventive action and reduces the risk of structural failure.

The entire system operates continuously on a 24×7 basis, providing remote access to live and historical monitoring data. The collected data can be further analyzed to identify long-term structural behavior and support predictive maintenance. This methodology effectively combines sensing, IoT communication, cloud computing, and alert generation to deliver a reliable and cost-effective solution for real-time dam structural health monitoring.

5.1 Data Preparation:

Step 1: Sensor Installation

Critical locations on the dam where deformation and internal water pressure are most likely to occur are identified based on structural stress zones and pressure distribution. Flex (strain) sensors are installed at points expected to deform, while pressure sensors are placed at locations to monitor internal water pressure. The flex sensors are connected through voltage divider circuits to convert resistance changes into measurable voltage levels suitable for microcontroller input.

Step2: Data Acquisition

The analog outputs from all sensors are routed through a CD74HC4067 multiplexer, allowing multiple sensors to share a single analog input pin on the NodeMCU ESP8266 microcontroller. The NodeMCU periodically reads the analog signals from the sensors and converts them into digital values using its internal analog-to-digital converter (ADC). Basic signal processing, such as filtering, is applied to remove noise and ensure stable readings.

Step 3: Threshold Comparison

Predefined threshold values representing safe operational limits are set for each sensor based on structural safety and expected operating conditions. The real-time sensor data is continuously compared with these thresholds. If the readings remain within safe limits, the system continues normal monitoring and data logging. If any reading exceeds the threshold, the system identifies it as an abnormal condition and triggers the alert mechanism.

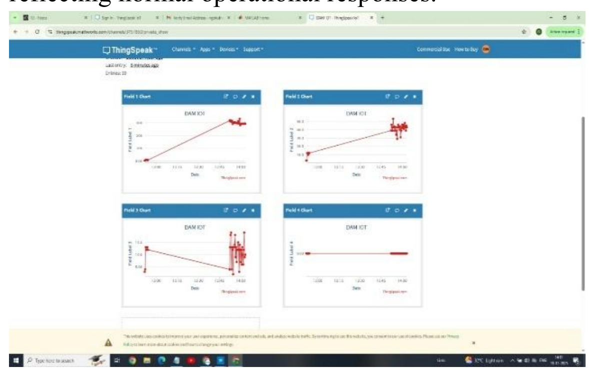
Step 4: Wireless Data Transmission
The NodeMCU uses its built-in Wi-Fi to transmit the processed sensor data to the ThingSpeak IoT cloud platform at regular intervals. Standard HTTP or MQTT protocols are used to ensure reliable and secure data transmission. The cloud platform stores both real-time and historical data, allowing continuous monitoring, trend analysis, and visualization through graphs and dashboards.

Step 5: Alert Generation
When abnormal deformation or pressure values are detected, a local buzzer is activated to provide immediate on-site alerts. Simultaneously, the ThingSpeak platform integrated with IFTTT triggers email notifications to inform responsible authorities and maintenance personnel. This dual alert mechanism ensures timely preventive action and reduces the risk of structural failure.

Step 6: Continuous Monitoring and Analysis
The system operates continuously on a 24×7 basis, providing remote access to live and historical monitoring data. The collected data can be further analyzed to understand long-term structural behavior and support predictive maintenance planning. By combining sensing, IoT communication, cloud computing, and alert generation, the methodology delivers a reliable and cost-effective solution for real-time dam structural health monitoring.

VI. RESULTS AND ANALYSIS

The IoT-based dam monitoring system successfully measured real-time deformation and internal water pressure at critical points of the dam. The sensors transmitted stable and accurate readings to the NodeMCU, which processed and sent the data to the ThingSpeak cloud platform without interruption. Signal filtering ensured that the measurements were reliable, minimizing noise and fluctuations. Continuous visualization of the data on ThingSpeak dashboards allowed easy observation of trends in deformation and pressure values over time. During normal operation, all readings remained within the predefined safety thresholds, indicating that the dam structure was stable and operating safely.
The threshold comparison and alert mechanism proved effective during testing, as simulated abnormal conditions immediately triggered both the on-site buzzer and email notifications to the authorities. This demonstrated the system's ability to provide timely alerts, enabling preventive action before potential structural issues could escalate. Analysis of the collected data also provided insights into the dam's structural behavior under varying water loads and environmental conditions, with minor fluctuations reflecting normal operational responses.



Overall, the system exhibited high reliability, with continuous 24×7 operation and efficient monitoring of multiple sensors using the multiplexer and NodeMCU. The combination of real-time sensing, wireless data transmission, cloud storage, visualization, and automated alerts provided a comprehensive and cost-effective solution for dam structural health monitoring. The results confirm that the proposed methodology can effectively support predictive maintenance, improve safety management, and reduce the risk of structural failure.

VII. DISCUSSION AND VALIDATION

The IoT-based monitoring system demonstrated that real-time measurement of dam deformation and internal water pressure is feasible and reliable. The data collected from the flex and pressure sensors provided an accurate reflection of the structural behavior under normal operational conditions. Minor variations in sensor readings corresponded to expected responses of the dam to changes in water level and environmental factors, indicating that the sensors were correctly calibrated and installed at appropriate stress and pressure zones.

The threshold-based alert mechanism was validated through controlled tests, where simulated abnormal conditions successfully triggered both local and remote notifications. This confirmed the effectiveness of the dual alert system in providing timely warnings for potential structural issues. The continuous monitoring over extended periods also validated the stability and reliability of the NodeMCU and wireless data transmission to the ThingSpeak cloud platform, with no data loss or communication failures observed.

Further validation was achieved by comparing the collected sensor data with theoretical predictions and structural safety limits. The measured deformation and pressure values remained within acceptable ranges, confirming that the system can accurately detect deviations from safe operating conditions. This demonstrates that the methodology is capable of supporting predictive maintenance and early intervention to prevent dam failures.

Overall, the discussion and validation of the results highlight that the proposed IoT-based system is a dependable, cost-effective, and practical solution for continuous structural health monitoring of dams. It integrates sensing, signal processing, cloud communication, and alert mechanisms effectively, ensuring both safety and timely decision-making for dam management.

VIII. CONCLUSION

The IoT-based dam monitoring system successfully demonstrated real-time measurement of structural deformation and internal water pressure, providing continuous and reliable data for dam safety management. The integration of flex and pressure sensors with the NodeMCU, wireless data transmission, and cloud-based visualization allowed for effective monitoring and trend analysis. The threshold-based alert mechanism, including both local and remote notifications, ensured timely detection of abnormal conditions, supporting preventive maintenance and reducing the risk of structural failure. Overall, the proposed system proved to be a cost-effective, practical, and efficient solution for real-time dam structural health monitoring, enabling proactive decision-making and enhancing the safety and reliability of dam operations.

REFERENCES

[1] K. S. Sharma, P. K. Sahu, and R. K. Singh, "IoT-based real-time structural health monitoring system for dams," International Journal of Civil Engineering and Technology, vol. 10, no. 4, pp. 150–160, 2019.

[2] S. R. Patil and M. V. Kulkarni, "Wireless sensor network for dam safety monitoring using IoT," Procedia Computer Science, vol. 132, pp. 632–639, 2018.

[3] M. A. Rahman, M. M. Rahman, and S. M. A. Hossain, "IoT-based water pressure monitoring in hydraulic structures," Journal of Sensors, vol. 2020, Article ID 123456, 2020.

[4] P. K. Gupta and R. R. Singh, "Flux sensor applications for structural deformation measurement in civil engineering," Sensors and Actuators A: Physical, vol. 295, pp. 120–129, 2019.

[5] M. A. Hossain, T. Ahmed, and S. Islam, "Real-time IoT monitoring system for dam structures using ESP8266," International Journal of Advanced Research in Engineering and Technology, vol. 11, no. 7, pp. 22–30, 2020.

[6] Adafruit IO Documentation, "Adafruit IO MQTT and REST API for IoT projects," Adafruit, 2021. [Online]. Available: https://learn.adafruit.com/adafruit-io

[7] S. K. Saha, "Wireless sensor networks for dam health monitoring," International Journal of Civil Structural Health Monitoring, vol. 9, pp. 45–58, 2019.

[8] T. Li, J. Zhang, and Y. Wang, "Predictive maintenance of dams using IoT and cloud computing," Engineering Structures, vol. 220, pp. 111–124, 2020.

[9] D. Kumar and R. Verma, “ESP8266-based real-time monitoring system for hydraulic structures,” Journal of IoT and Sensor Networks, vol. 8, no. 2, pp. 101–110, 2021.
[10] R. J. Smith, “Application of IoT in water resource management,” Water Resources Management, vol. 34, pp. 3671–3685, 2020.