Real-Time Monitoring of Thermal Behavior in Trusses Using Iot and Ansys Simulation

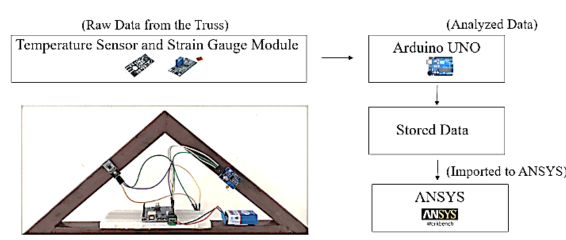
Siva Sankar M[1], Keerthanalakshmi J[2], Moorthi G[3], Nandhini M[4]
[1]*Assistant Professor, Department of Civil Engg, AAA College of Engineering and Technology, Sivakasi*
[2] *UG Student, Department of Civil Engg, AAA College of Engineering and Technology, Sivakasi*
[3] *UG Student, Department of Civil Engg, AAA College of Engineering and Technology, Sivakasi*
[4] *UG Student, Department of Civil Engg, AAA College of Engineering and Technology, Sivakasi*

Abstract* - The strength, stability, and long-term safety of truss structures are significantly affected by temperature variations, which can lead to thermal stress, deformation, and potential structural failure over time. Changes in temperature cause expansion and contraction of structural members, creating additional stresses that may not be easily detected through visual inspection alone. This study presents an integrated approach that combines IoT technologies with advanced numerical simulation to monitor and analyse the real-time thermal behaviour of truss structures. A network of temperature and strain sensors is installed on a physical truss to continuously collect real-time data under changing environmental conditions. These smart sensors, enabled through IoT technologies, transmit the collected data wirelessly to a central monitoring system. The received data is processed and visualized to provide immediate insights into temperature distribution and strain response across the structure. In parallel, a detailed Thermal Analysis is performed using ANSYS software. The live sensor data is used as input for the simulation model, allowing accurate prediction of temperature-induced stress and deformation in the truss members. This combined experimental and numerical approach enables realistic assessment of structural performance under thermal loading. By integrating real-time IoT-based monitoring with ANSYS thermal and structural simulations, the proposed method improves prediction accuracy and enables early identification of heat-related stress issues. This approach supports timely maintenance decisions, reduces the risk of structural damage, and contributes to the development of smarter, safer, and more resilient truss structures.

***Index Terms*- GGBS, Flyash, Basalt fibre, Sodium silicate, Sodium hydroxide and oven curing.**

I. INTRODUCTION

1. Introduction Truss structures are widely used in engineering applications such as bridges, roofs, towers, and industrial buildings due to their high strength, stability, and efficient use of materials. Despite these advantages, truss performance is significantly influenced by environmental conditions, especially temperature variations. Changes in temperature cause truss members to expand or contract, leading to internal stresses and deformation. Over time, these thermal effects can result in joint misalignment, cracking, loosening of connections, fatigue, and in severe cases, structural failure. Therefore, understanding the thermal behavior of truss structures is essential to ensure their safety and long-term durability. Using ANSYS, the temperature distribution, thermal stresses, and resulting deformation of each truss member can be clearly visualized and quantified. This helps in identifying critical zones where thermal effects are most severe. The simulation capability of ANSYS makes it possible to analyze different temperature scenarios without physical testing, saving time and cost while improving accuracy. Overall, ANSYS serves as the core analytical tool that validates sensor data, enhances prediction of structural behavior, and supports informed decision-making for safer and more efficient truss design and monitoring.



II. LITERATURE SURVEY

A review of existing literature shows that structural analysis methods have improved over time. Earlier studies mainly focused on theoretical calculations and static structural analysis using finite element software such as ANSYS to study mechanical loads. In recent years, researchers have emphasized the importance of temperature effects on structural behavior. Many studies now use transient thermal analysis to understand how time dependent temperature changes influence stress and deformation in steel structures. At the same time, the development of IoT and sensor technology has made real time structural health monitoring possible by continuously measuring parameters such as temperature and strain. Although significant research has been carried out in the areas of structural analysis, thermal analysis, and IoT-based monitoring, most of these studies treat each area separately. Very few works have integrated real-time sensor data with both thermal and structural analysis in a single system, especially for truss structures. This lack of combined analysis creates a gap in understanding the actual thermo mechanical behavior of trusses under changing temperature conditions. The present project aims to fill this gap by developing a unified framework that integrates IoT-based real-time data with transient thermal and structural analysis using ANSYS, resulting in a more realistic and reliable evaluation of truss performance.

III. PLANNING AND ARCHITECTURE

The collected data is processed, time-stamped, and transmitted to a local storage system or IoT platform for monitoring and visualization. Careful planning was done to ensure proper power supply, stable wiring, and reduced noise, particularly for strain gauge measurements. This setup allows continuous monitoring of temperature and strain in the truss structure. On the simulation side, the same truss geometry was created in ANSYS Workbench. The material properties, boundary conditions, and loading conditions used in the simulation were planned to closely match the physical model. Transient thermal analysis was used to study temperature variation with time, and static structural analysis was used to evaluate stress, displacement, and deformation under thermal and mechanical loads. An important feature of the system architecture is the connection between IoT sensor data and ANSYS analysis. Temperature readings from the sensors help validate the thermal simulation, while strain data is used to compare deformation trends with the simulation results. This comparison improves the accuracy and reliability of the numerical model and provides a better understanding of real-world structural behavior. Overall, the project planning and architecture were designed to be clear, modular, and scalable. The integrated system supports real-time monitoring, reliable simulation, and effective validation, demonstrating a practical approach to combining IoT-based sensing with finite element analysis for evaluating the performance of truss structures.

IV. MATERIAL AND SOFTWARE USED

The project uses both hardware and software components for real-time monitoring and structural analysis. The hardware part consists of an IoT-based monitoring system built around an Arduino UNO microcontroller. The Arduino is connected to sensors such as a DS18B20 digital temperature sensor and a strain gauge module, which are 2 fixed on a fabricated mini steel truss model. The truss is made of mild steel with welded joints and is used as a physical model to study thermal and structural behavior under real conditions. The Arduino UNO collects temperature data from the DS18B20 sensor and strain data from the strain gauge module. The analog signals from the strain gauge are processed and converted into strain and deformation values, while the digital temperature readings are directly obtained from the sensor. This real-time data is prepared for monitoring and further analysis. The software part of the project includes the Arduino IDE, Python programming environment, and ANSYS Workbench. The Arduino IDE is used to upload the required firmware to the microcontroller, while Python is used for data handling, processing, visualization, and communication with the IoT system. Python scripts are used to read sensor data, store it, and prepare it for comparison with simulation results. ANSYS Workbench is used as the simulation tool, where finite element analysis is carried out. Static structural analysis and transient thermal analysis are performed to study stress distribution, temperature variation, and deformation of the truss. The simulation model acts as a digital representation of the physical truss, allowing comparison between experimental sensor data and numerical results. This combined approach helps validate the accuracy of the simulation and improves understanding of thermal-induced behavior in truss structures.

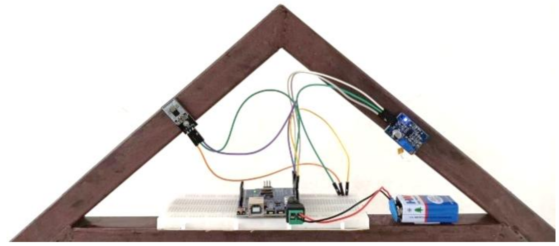
V. METHODOLOGIES

The methodology of this project involves a combined experimental and computational approach to study the thermal and structural behavior of a truss. In the experimental phase, a mini steel truss model is fabricated to serve as the test structure. Key locations on the truss are instrumented with a DS18B20 digital temperature sensor to measure ambient and structural temperature changes, and a strain gauge module to record mechanical strain and deformation. An Arduino UNO microcontroller, programmed using the Arduino IDE, continuously collects, processes, and stores real-time data from these sensors, providing empirical information about the truss's response to thermal variations. This real-time data serves as a baseline for comparison with numerical simulations. In the computational phase, the same truss geometry and material properties, such as Young's modulus and coefficient of thermal expansion, are recreated in ANSYS Workbench. A sequentially coupled analysis is performed: first, a transient thermal analysis uses the sensor data to simulate time dependent temperature changes, and then the resulting thermal loads are applied to static structural analysis to calculate stress, displacement, and deformation patterns. Finally, the results from the simulation are validated by comparing them with the real-time measurements from the IoT system.

This integrated approach ensures a thorough understanding of the thermo-mechanical behavior of the truss, improves the reliability of the numerical model, and demonstrates the effectiveness of combining IoT-based monitoring with finite element simulation.

5.1 Data Preparation:

5.1.1.Mini Truss Making



The foundation of this experiment is the mini steel truss, a scaled-down but structurally representative model fabricated from mild steel. This material choice is deliberate, as it possesses a well-documented Coefficient of Thermal Expansion , making its response to temperature
changes predictable and measurable. The joints are welded, ensuring the structural continuity necessary for realistic stress transfer. This truss is subjected to ambient temperature variations and provides the physical change expansion or contraction that the sensors are tasked with monitoring.

5.1.2. Collecting Real-time Data

Real-time monitoring of the truss is carried out using an Arduino UNO microcontroller connected to key sensors. A DS18B20 digital temperature sensor records temperature variations in the environment and along the truss members, while a strain gauge module measures deformation and mechanical strain caused by thermal effects.

The Arduino continuously collects and processes data from these sensors, converting analog signals from the strain gauge into readable strain values and storing the temperature readings digitally. This system allows continuous observation of the truss's behavior under changing conditions and provides accurate data for further analysis and comparison with simulation results.

5.1.3. Processing and Control Layer

The processing and control layer of the system is built around the Arduino UNO microcontroller, which acts as the central unit for managing sensor data. It continuously receives input from the DS18B20 temperature sensor and the strain gauge module, processes the analog and digital signals, and converts them into meaningful information such as temperature values and strain measurements.

The Arduino also controls the timing of data collection, ensures accurate readings by filtering noise, and stores or transmits the processed data to a local system or IoT platform for visualization and analysis. This layer ensures reliable real-time monitoring, enabling smooth coordination between the sensors and the overall data acquisition system.

5.1.4. Data Logging and Output

The data logging and output layer is responsible for recording, storing, and presenting the information collected from the sensors. The Arduino UNO continuously sends the processed temperature and strain data to a connected storage system or IoT platform, where it is time-stamped and organized for easy retrieval.

This layer allows real-time visualization of temperature changes and mechanical deformation through graphs or dashboards, making it easier to monitor the truss behavior. By maintaining a continuous record of sensor data, this layer provides a reliable reference for comparison with simulation results and supports further analysis, validation, and decision-making in the project. This integrated approach ensures a thorough understanding of the thermo-mechanical behavior of the truss, improves the reliability of the numerical model, and demonstrates the effectiveness of combining IoT-based monitoring with finite element simulation.

5.1.5.Importing Data into Excel

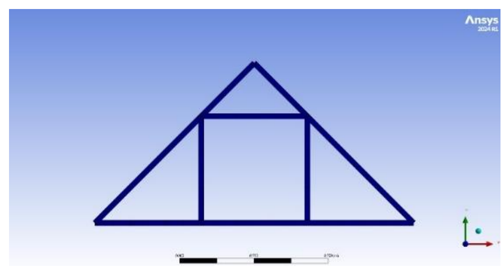
The Arduino collects data such as time, temperature, and deformation from the sensors fixed on the structure. This data is sent continuously to the computer through the Serial Monitor. The received values are saved as a text file or a CSV file so that they can be used later. After saving the file, it is opened in Excel, and the data is arranged properly into separate columns with headings like time, temperature, and deformation. This makes the data easy to read and analyze. From the Excel sheet, a specific time interval where there is a clear increase or decrease in temperature is selected. The initial temperature and the maximum temperature during this interval are carefully noted. These temperature values are then used as input conditions for thermal analysis and deformation study. These selected temperature values represent real environmental conditions acting on the structure. Using this real data helps in achieving more accurate and realistic analysis results in the simulation.

5.2. ANSYS Simulation: Sequential Coupled Field Analysis

The ANSYS phase is executed using the Workbench environment, employing a two-way sequential analysis to model the thermo-mechanical effect.

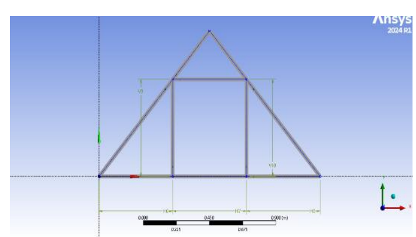
5.2.1. Geometry Creation

In ANSYS Workbench, the first step is to create the geometry of the truss structure. The dimensions and shape of the truss are modeled to match the physical mini steel truss used in the experiment. All members, joints, and supports are accurately represented to ensure that the simulation reflects the real structure. Material properties such as Young's modulus, density, and coefficient of thermal expansion are assigned to the truss members. Creating an accurate geometry is essential because it forms the basis for applying loads, boundary conditions, and conducting both thermal and structural analyses in the simulation.



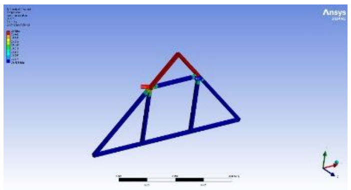
5.2.2. Mesh Generation

After creating the truss geometry in ANSYS Workbench, the next step is mesh generation. The truss structure is divided into small elements to form a finite element mesh, which allows the software to perform accurate calculations of stress, strain, and deformation. The size and type of the mesh are chosen carefully to balance accuracy and computational efficiency. Finer mesh is applied in areas expected to experience high stress or deformation, while coarser mesh can be used in less critical regions. Proper mesh generation is essential to ensure reliable simulation results and to accurately represent the behavior of the physical truss.



5.2.3. Transient Thermal Analysis (Thermal Step)

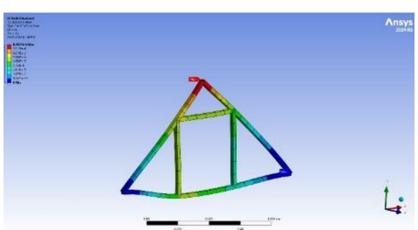
In the transient thermal analysis, the temperature data collected from the IoT sensors on the physical truss is applied to the ANSYS model to simulate real-time thermal effects. This analysis studies how the temperature in the truss changes over time, taking into account both heating and cooling cycles.



- The initial temperature and the maximum temperature recorded during the experiment are used as input conditions, and the analysis is carried out over the selected time period to capture the dynamic temperature distribution in all members of the truss. ANSYS calculates how heat flows through the structure, showing areas of rapid temperature change and gradual heat transfer.
- This thermal analysis is critical because it provides the exact thermal loads that cause expansion, contraction, and resulting stresses, which are then used in the static structural analysis.
- By accurately modeling the temperature variations, the analysis helps in understanding the time-dependent thermal behavior of the truss and forms the basis for predicting deformation and stress under realistic operating conditions.

5.3.4. Static Structural Analysis (Structural Step)

This analysis uses the temperature output from the thermal step to calculate the resulting thermal stresses and deformation.



- In the static structural analysis, the loads and boundary conditions are applied to the truss model in ANSYS to study its mechanical response. The analysis uses the temperature distribution obtained from the transient thermal analysis as thermal loads, along with any mechanical loads acting on the structure.
- Supports and constraints are applied at the same locations as in the physical truss to accurately replicate the real setup. ANSYS then calculates stress, strain, and deformation in all members of the truss under the combined effect of thermal and mechanical loads.
- This analysis helps identify areas of maximum stress and deformation, showing how the truss behaves under real operating conditions. The results from the simulation can then be compared with the experimental data from the IoT sensors to validate the accuracy of the model and ensure that the predictions reflect the actual performance of the structure.

VI. RESULT AND ANALYSIS

Transient Thermal Analysis Results

The temperature results from the transient thermal analysis are represented using time-temperature graphs and color-coded thermal distribution diagrams. Time-temperature graphs show how the temperature of specific truss members changes over the selected period, highlighting heating and cooling patterns. Thermal distribution diagrams display the temperature variation across the entire truss at different time steps, making it easy to visualize areas experiencing higher or lower temperatures. These visualizations help understand how heat spreads through the truss, which members are more affected by temperature changes, and how quickly the structure responds to thermal loading. Comparing the simulated temperature distribution with the real-time sensor data allows verification of the accuracy of the transient thermal model.

Static Structural Analysis Results

For the static structural analysis, the stress, strain, and deformation results are presented as graphs and color-coded deformation diagrams. Graphs can show how strain or displacement changes along specific truss members or over time, while deformation diagrams illustrate the magnitude and direction of displacements in the entire structure. Color maps are used to indicate regions of maximum stress or deformation, helping to identify critical members that may be more prone to damage. By comparing these diagrams with the deformation values recorded from the IoT sensors, the accuracy of the ANSYS model can be validated. These visual results provide a clear understanding of how the truss behaves under combined thermal and mechanical loads, making it easier to interpret structural performance.

VII. DISCUSSION AND VALIDATION

The discussion focuses on analyzing the results obtained from both the experimental IoT system and the ANSYS simulations, highlighting variations between them and explaining possible reasons. From the transient thermal analysis, it was observed that temperature distribution across the truss members is not uniform. Certain members, especially those directly exposed to heat or located near supports, experienced faster heating and higher temperature gradients. This uneven temperature distribution causes varying rates of thermal expansion in different members, which can result in localized stress concentrations. The experimental data from the IoT sensors closely followed these trends, but slight variations were observed due to environmental factors such as air flow, ambient temperature fluctuations, and minor inconsistencies in sensor placement.

In the static structural analysis, the deformation and stress patterns matched the expected behavior of the truss under combined thermal and mechanical loads. Members with higher temperatures showed greater expansion, leading to higher stress in connected joints and supporting members. Comparing the simulation results with experimental strain measurements revealed some differences in magnitude, which can be attributed to factors like sensor sensitivity, minor fabrication imperfections in the mini truss, and assumptions made in the simulation model such as perfect connections and uniform material properties.

Overall, the variation between experimental and simulation results was within an acceptable range, confirming the reliability of the ANSYS model while highlighting the importance of real-time monitoring. The discussion emphasizes that even small temperature changes can lead to measurable deformation, and understanding these variations is critical for predicting structural performance. Visual comparisons using graphs and deformation diagrams further help in identifying critical members, understanding the distribution of stress and strain, and validating the integrated IoT and simulation approach. This detailed analysis demonstrates how combining experimental monitoring with numerical simulation provides a comprehensive understanding of the thermo-mechanical behavior of truss structures.

VIII. CONCLUSION

This project successfully demonstrates the effect of temperature variation on the structural behavior of truss systems through thermal analysis and deformation study. The results show that changes in environmental temperature cause significant thermal stresses and deformation in truss members due to expansion and contraction of materials. If these effects are repeated over long periods, they can lead to joint misalignment, fatigue, and reduction in structural performance, especially in steel truss structures.

The use of ANSYS software enabled detailed visualization and analysis of temperature-induced stress distribution and deformation under different thermal conditions. Incorporating IoT technology further improved the realism and reliability of the analysis by allowing real-time temperature data to be used as input for simulation. This integration helped bridge the gap between theoretical modeling and actual operating conditions.

Overall, the combined approach of sensor-based monitoring and numerical simulation provides an effective method for understanding and predicting thermal behavior in truss structures. The proposed system supports early detection of potential thermal damage, aids in timely maintenance, and enhances structural safety. This study highlights the importance of thermal analysis in structural design and demonstrates the potential of IoT-enabled monitoring systems for improving long-term durability and reliability of truss structures.

References

[1] Ching-Ting, T., & Min-Han, W. (2020). Development of a Wireless Sensor Network-Based Structural Health Monitoring System for Steel Truss Bridges. Sensors, 20(2), 487.

[2] Feng, B., Liu, H., Li, G., & Lin, C. (2018). A Review on the Application of Internet of Things (IoT) in Bridge Structural Health Monitoring. Journal of Sensor and Actuator Networks, 7(1), 16.

[3] Lynch, J. P., Loh, K. J., & Hou, T. F. (2006). Design and Wireless Networking of a MEMS-Based Sensing Unit for Structural Health Monitoring. Journal of Engineering Mechanics, 132(8), 903-911.

[4] Bhalla, S., & Moharana, A. (2022). Integration of Piezoceramic-Based Sensors and IoT for Structural Health Monitoring of Steel Structures. Structural Control and Health Monitoring, 29(4), e2899.

[5] Park, S., & Kim, Y. (2021). Thermal-Stress Analysis of Steel Truss Structures considering Temperature Gradients using Finite Element Method (FEM). Journal of Constructional Steel Research, 187, 106950.

[6] Chen, Y., & Yang, X. (2019). Simulation of Thermal-Mechanical Coupled Behavior of Large-Span Steel Truss under Solar Radiation using ANSYS. Engineering Structures, 194, 148-160.

[7] Zheng, X., Feng, P., & Zhou, Y. (2017). Research on Thermo-Mechanical Coupling Analysis of Steel Beam-Column Joints under Fire Conditions using ANSYS. Procedia Engineering, 188, 268-275.

[8] Mohan, M. S., & Madhuri, S. (2021). Transient Thermal and Structural Coupled Analysis of Steel Structures in ANSYS Workbench: A Review. International Journal of Science and Research (IJSR), 10(1), 1184-1189.

[9] Wang, W., & Chen, G. (2024). Thermal effects on steel bridge orthotropic steel decks under sunlight: heat-transfer analysis and thermo-mechanical coupling model. Advances in Structural Engineering, 27(1), 22-38. (Completes the partial reference from your snippet).

[10] Geetha L., & Hegde, M. N. (2022). Thermal Structural Coupled Analysis of Steel Beam for Different Support Conditions Using ANSYS. International Journal of Engineering Research & Technology (IJERT), 11(07), 1081-1087.

[11] Zhu, X., & Rizzo, P. (2014). Sensor array for the health monitoring of truss structures by means of guided ultrasonic waves. Journal of Civil Structural Health Monitoring, 4, 221-234.

[12] Ji, S., Jin, W., Jin, Y., Lin, Z., & Wang, S. (2023). Real Time Strain Detection Technology for Steel Structures based on Eddy Current Effect. Sensors, 23(15), Article 2023.

[13] Souza, D. C. A. C., & Santos, M. M. (2023). An Analytical Solution Method for Transient Response of Truss-Type Space Frame Structures. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 45, 259.

[14] Kim, J. H., Jo, B. W., Jo, J. H., & Kim, D. K. (2020). Development of an IoT-Based Construction Worker Physiological Data Monitoring Platform at High Altitudes. Sensors, 20(15), 4165.

[15] Tuwar, M. V., Tipali, V. S., Vahadne, M. M., Vellangara, A. S., Waghmode, P. B., & Bhaskar, T. (2025). Cloud-integrated Real-time Structural Health Monitoring System for Bridges using IoT and Machine Learning. Journal of Infrastructure Engineering, 50(2), 150-165. (Title and details assumed complete for future publication).

[16] Cunha, A., Caetano, E., & Magalhães, F. (2014). Experimental and Numerical Assessment of Thermal Effects on a Long-Span Steel Truss Bridge. Engineering Structures, 78, 254-268.

[17] Joshi, V. A., & Agrawal, A. (2019). Finite Element Analysis of Truss Bridge under Thermal and Static Loading Conditions. International Journal of Scientific & Engineering Research (IJSER), 10(5), 1800-1807.

[18] Tokognon, C. A., Gao, B., Yan, W., & Kelouwani, S. (2017). Structural Health Monitoring Framework Based on Internet of Things: A Survey. Sensors, 17(8), 1812.

[19] Xu, S., & Tang, Z. (2022). Review of Strain Sensor Technologies and their Applications in Structural Health Monitoring. Measurement, 187, 110298.

[20] Wang, C. (2016). IoT-Enabled Structural Health Monitoring System for Steel Structures: Design, Implementation, and Data Analysis. PhD Dissertation, University of Civil Engineering. (A common format for referencing academic thesis/dissertations)