# CONDITION ASSESSMENT AND MONITORING OF RC STRUCTURAL ELEMENTS SUBJECTED TO EARTHQUAKES AND HIGH TEMPERATURE DUE TO FIRE ADOPTING IOT WIRELESS SENSOR SYSTEMS

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**Keywords:**

Structural Health Monitoring, IoT, wireless, accelerometer, thermocouple, RC structure, Thingspeak.

**Introduction:**

Structural health monitoring (SHM) is the process of monitoring the response of the structure (displacements, rotations, temperature) and determining damage taken place in the structure. The major factors in this area are to improve safety, optimize, maintenance operations, predict and extend the structure's life. The sensors used for monitoring are accelerometers in the case of vibration and thermocouples in case of high temperature exposure. These sensors work on IoT based wireless networks to acquire the data of displacement through accelerometers when vibrations are induced and the temperature is sensed through the thermocouple when there is breakout of fire.

(Valinejadshoubi et al., 2016) used multiple sensors including eight strain gauges, two thermocouples and one accelerometer which were placed on a beam in this study and modal analysis and finite element modeling was carried out to investigate how damages on structural elements can be detected.

(Navabian & Beskhyroun, 2020) introduced a wireless smart sensor network and MATLAB- based data management. Several laboratory and field experiments were conducted to evaluate the performance and the results showed high resolution and sensitivity of the wireless smart sensor nodes were similar to the wired sensors.

(Muttillo et al., 2020) designed a node composed of an accelerometer, a microcontroller, and an external storage. The accelerometers were set up on a cantilever structure (Al bar). The proposed monitoring system eliminated problems found in traditional analog sensors and was cheaper. It also allowed for the measurement of the main parameters for evaluating the damage indicators.

(Kim et al., 2019) conducted a comparative study of the wireless and wired network of thermocouples fitted on the steel column. Wireless network was seen to be cost effective and able to handle larger amounts of data given correct selection of radio propagation path.

**Objectives:**

The project aims to develop an IoT based system for structural health monitoring of real time damage detection in reinforced concrete (RC) structural elements:

1. The IoT based wireless system is adopted as a part of structural health monitoring, and considers a wireless accelerometer sensor to acquire inter-story displacements in reinforced concrete (RC) structures, subjected to lateral loads such as earthquakes and wind in the present work.
2. A wireless temperature sensor is also considered in the present work to acquire and measure the temperature in an RC structural member that is exposed to high temperature in the event of an accidental fire (fire followed by an earthquake when gas pipelines are ruptured during the event of earthquakes).
3. Wireless sensor system is adopted to acquire and measure storey displacements and temperature within an RC structural member adopting IoT techniques. The data acquisition system used is based on a cloud platform(Thingspeak) that uses secure API communication so the displacement and temperature response in the structure can be acquired remotely through wireless sensors that are embedded in the RC structural elements.

**Methodology:**

1. A wireless sensor network consisting of an ADXL345 accelerometer was designed using ESP32 Wi-Fi/BT enabled microcontroller was designed to detect and analyze storey displacement in an RC structure and monitor the status to prevent catastrophic failure. A cloud server is used for data recording and analyzing with the help of MATLAB. To test the functionality of the system, a scaled 3D steel frame model is mounted on a shake table and subjected to scaled earthquake loads (from existing data).
2. A wireless temperature sensor system is also considered in the present work to acquire and measure the temperature in an RC structural member that is exposed to high temperature in the event of an accidental fire. The sensor node consists of k-type thermocouples and ESP32 microcontroller, and a similar cloud-based network is used for data acquisition and storage. The system is tested on reinforced concrete beams of M25 grade which are exposed to high temperatures of 300°C, 450°C and 600°C adopting a furnace of required dimensions. The thermocouples are embedded in the specimen at various depths to acquire the temperature readings across the cross-section of the beam. These beams are then subjected to 4-point loading in displacement control mode up to failure to assess the load carrying capacities of such thermally damaged RC beams.

3. Finite element analysis is carried out to validate the material model and the finite element model with respect to the experimental results adopting ABAQUS to confirm said experimental results of displacements and temperature measured using wireless sensors and to further carry out parametric studies in real time structure/structural members.

**Work carried out:**

1. Mix design of the concrete was tested for various water/cement ratios by casting 150mmx150mm cubes and cylinders with diameter of 75mm and 50mm. These specimens were tested for compression and split tensile strength at 7, 14 and 28 days of curing with the aim of achieving approximately 60%, 80% and 100% of the design strength respectively.

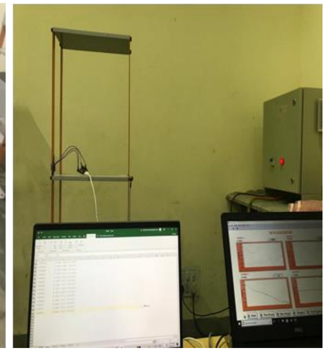


2. The functionality and accuracy of the k-type thermocouples and sensor network was tested by
   a. Exposing directly to a flame and checking the temperature obtained
   b. 2 concrete cubes of 75mmx75mm were cast for the purpose of heating. An approx 1cm hole was drilled in the center and the cubes were heated to a temperature of 400°C. The thermocouples were inserted in the cube after removal and the temperature was measured, taking into account heat loss.

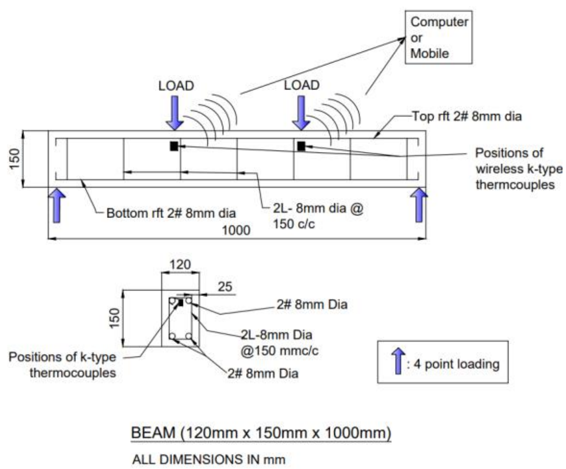

3. The precision of the accelerometer readings to obtain displacement values was tested by mounting the sensor network on a scaled 3D steel frame model which was mounted on a shake table and subjected to scaled earthquake loads (from existing data). The data from ADXL345 accelerometers was compared with the data acquired from piezoelectric

accelerometers to evaluate the difference in accuracy and delay of the readings on the data acquisition platform.





4. 4 RC beams of 120x150x1000mm size were cast using M25 grade concrete. The details of the beam are given below. 3 beams are to be exposed to high temperatures of 300°C, 450°C and 600°C adopting a furnace while 1 beam is left as the control beam. Two thermocouples were embedded in each of the 3 beams at depths of 25mm (cover) and 60mm





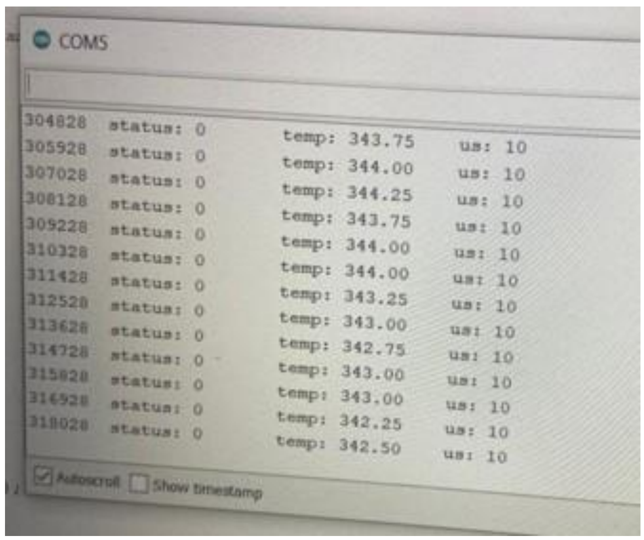
**Results/Conclusions:**

1. For W/C ratio 0.52, strength obtained was:
   Design Strength: 31.6 N/mm$^2$

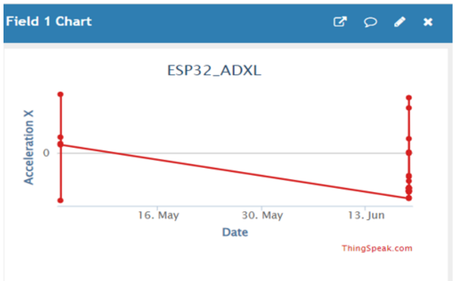
| | 7 days | 14 days | 28 days |
|---|---|---|---|

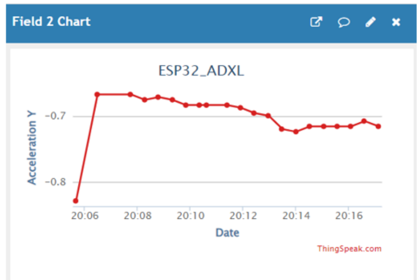
| | | | |
|---|---|---|---|
| Compressive strength (cubes - 150x150mm) | 20.71 N/mm$^2$ (65.53%) | 23.98 N/mm$^2$ (76%) | 27.03 N/mm$^2$ (85.54%) |
| Split tensile strength (cylinders - 50 mm dia) | 1.24 N/mm$^2$ | 1.87 N/mm$^2$ | 2.65 N/mm$^2$ |
| Split tensile strength (cylinders 75 mm dia) | 2.28 N/mm$^2$ | 2.5 N/mm$^2$ | 2.77 N/mm$^2$ |

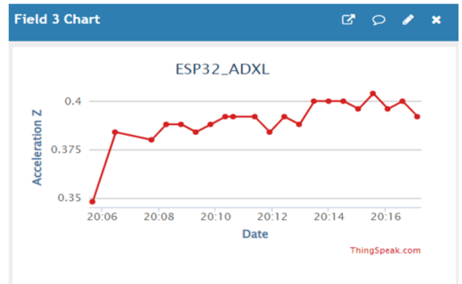
2. The thermocouples were inserted in the cubes immediately after removal from the furnace, which was heated to a temperature of 350°C for one hour. The temperature obtained inside the cube that was sensed by the wireless thermocouple was 343°C. This difference in temperature could be attributed to the natural heat loss after removal of the concrete cube from the oven.




3. Accelerometer data obtained:
   Accelerometer data was acquired on data acquisition/cloud platform, Thingspeak, wirelessly with the use of Wi-fi. The data was then transferred to Matlab and FFT analysis was carried out. Post processing was performed on the acceleration data obtained in the frequency domain (through FFT) to get velocity and position data.
   Due to Thingspeak constraints, a delay of 15 seconds is noted while transmitting the data from the client to the server.
   The figures show the graphical output on the Thingspeak cloud and is able to observe only after logging in the Thingspeak website with the help of created username and password and the cloud provides a reliable output.
   This low cost solution paves the way towards cloud platforms with better efficiency and reasonable delay.








**Scope of future work:**

1. Measurement of storey displacement and temperature variation in real-life multi-storey structures.
2. Assessment of damage when the structure is subjected to different temperatures and time of exposure.
3. To carry out damage assessment of a structure by a remote mode adopting wireless sensors and IoT systems when a structure is:
    a. Subjected to lateral displacement due to earthquake
    b. Exposed to high temperature in the event of a fire