

# Multi-Hazard Resilient Building Design Incorporating Earthquake, Wind, and Flood Resistance Using Smart Engineering Technologies

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## ABSTRACT

Natural hazards like earthquakes, high winds and floods are critical to the life and operability of the built structures. A multi-hazard resilient design framework is presented using smart engineering systems, IoT-based SHM and CNN-LSTM based hybrid deep learning model for detecting real-time damage and early warning. Finite element method simulation was conducted by developing G+10 RC building structure and subjecting it to the dynamic earthquake, wind and flood actions. The framework showed improved performance over conventional structure design: 31.69% reduction in earthquake induced displacement, 32.93% reduction in wind induced roof displacement and 41.63% reduction in foundation settlement. IoT based SHM exhibited a good sensor accuracy of 98.42%, data transmission rate accuracy of 99.13% and alert generation accuracy of 97.86%. The hybrid CNN-LSTM model produced a very good damage prediction accuracy of 97.84%, which indicates anomaly identification and quick decision making.

**KEYWORDS:** Multi-hazard resilient design, CNN-LSTM, SHM, IoT.

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## 1. INTRODUCTION

Natural disasters have become increasingly frequent and severe due to rapid urbanization, climate change, environmental degradation, and population growth [1]. Earthquakes, strong wind and floods are responsible for significant human, economic and infrastructure losses globally among all the hazards threatening the built environment [2]. Traditional designs aimed at mitigating one hazard may fail to take into account the possibility of multiple hazards happening at once or one following another, creating a vulnerability for the building when they happen together [3]. With the increasing pace of urbanization, cities are becoming more vulnerable to hazards, especially those that are increasingly becoming common, and the need for resilient building systems that can withstand a range of hazards and remain intact and useful is increasing [4]. Therefore, multi-hazard resilient building design has gained much attention as a key research and development field in civil and structural engineering.

Earthquakes create dynamic ground motion that exert large lateral forces on buildings, causing damage, collapse and loss of life frequently [5]. High pressure differentials and uplift forces associated with wind hazards, such as hurricanes, cyclones and severe storms, can affect structural stability and building envelopes [6]. Floods, however, can result in hydrostatic and hydrodynamic pressures, foundation erosion, infiltration, and degradation of materials [7]. These hazards interact, resulting in compounding engineering challenges which can be difficult to address because a structure that is robust against one hazard may not be as effective against another [8]. Hence, it is important to have a complete design framework that will incorporate resistance to earthquake, wind loads and flood impact to guarantee long term safety and sustainability.



**Figure 1.1: Multi-hazard resilient building**

Resilience is not just about building strength, it is a concept that focuses on the ability of a building to withstand disturbances, adapt to changing conditions and recover quickly from a disaster event [9]. Resilient buildings are intended to prevent catastrophic loss, as well as to continue to serve as a functional building during and after hazardous events [10]. This approach needs to be comprehensive knowledge about the structural behavior, material performance, risk assessment and disaster mitigation strategies [11]. Multi-hazard resilience combines all these aspects in a single design process, allowing buildings to function effectively in multiple loading situations and environments.



**Figure 2: Multi-Hazard Resilient Building Design Incorporating Earthquake, Wind, and Flood Resistance Using Smart Engineering Technologies**

In earthquake resistant construction, intelligent damping systems, base isolation techniques and adaptive control systems mitigate structural responses and energy dissipation requirements [12]. In wind resistant design,

aerodynamic optimization, active control systems and intelligent facade technologies enhance stability and comfort in extreme winds [13]. Flood resistant designs employ elevated foundations, flood walls, permeable building materials and automated drainage systems to reduce water damage. The integration of these smart engineering technologies within a single structure creates an adaptable and resistant system that addresses a wide range of hazards [14].

Additionally, the development of computational modeling, BIM, digital twin, and simulation-based design has allowed engineers to assess the performance of buildings under hazardous conditions with higher precision. Using such advanced techniques allows engineers to optimize designs, materials, and mitigate hazards with minimal uncertainty. In view of using the latest technology and applying resilience to designs, it becomes possible to develop infrastructure that is safe, sustainable, and affordable for future generations.

The main purpose of this investigation is the development and analysis of a multi-hazard resilient design framework of building considering earthquake, wind and flood through use of smart engineering techniques. This investigation presents evaluation of improved structural systems and smart monitoring techniques which would enable efficient building performance under varying hazard environments. The outcome is hoped to improve the research area related to resilient infrastructure development and establish safer buildings to cope with complex natural disasters. Here are the research objectives of the study follows as:

- To create a multi-hazard resilient building design framework which could withstand the effects of seismic, wind and flood hazard based on novel structural engineering principles.
- To analyze the effect of seismic, wind and flood loads on the structural integrity of a G+10 RC building with the help of numerical simulation and finite element analysis.
- To design and implement an IoT-based SHM system which could monitor the behavior of the structural and environmental attributes at real time during hazards.
- To devise a hybrid CNN-LSTM deep learning algorithm for Structural damage detection, anomaly detection, and early warning generation on the basis of collected sensor data from SHM system.
- To evaluate structural behavior of the proposed building for multi-hazard loading in terms of displacement, inter-story drift, stress distribution, base shear and structural damage index.
- To analyze efficiency of IoT enabled monitoring system in damage detection accuracy, response time, alert generation and support system for the disasters.

## 2. Related Work

Based on the reviewed literature, recent studies have demonstrated significant progress in integrating digital technologies such as Digital Twins, Building Information Modeling (BIM), Geographic Information Systems (GIS), Internet of Things (IoT), Artificial Intelligence (AI), and Structural Health Monitoring (SHM) for multi-hazard resilience assessment. Qi et al. (2026) [15] developed a digital twin-based monitoring framework for transmission towers subjected to wind and flood scour hazards, while Dilmen et al. (2026) [16] introduced a machine learning-driven GIS-AHP model for wind turbine site selection considering earthquake–landslide interactions. Similarly, Rahimi et al. (2025) [17] proposed a multi-hazard digital twin framework incorporating earthquake and flood loading for urban infrastructure resilience evaluation. Ugliotti et al. (2025, 2024) [18,19] developed the TERIMAAS framework by integrating GIS, BIM, and IoT technologies to assess hazard risks at both territorial and building scales, whereas Faraji et al. (2025) [20] utilized AI-enabled SHM systems for enhancing the resilience of urban water and flood management infrastructure. Furthermore, Esmailzadeh et al. (2024) [21] employed GIS and multi-criteria decision-making techniques to evaluate community-level vulnerability and livelihood resilience against earthquakes, floods, and droughts. Collectively, these studies highlight the growing importance of intelligent monitoring systems, real-time data integration, and digital platforms in improving infrastructure resilience under multiple hazard conditions.

Despite these advancements, several critical research gaps remain. Most existing studies focus on the interaction of only two hazards, such as earthquake–flood or earthquake–landslide scenarios, while the combined influence of multiple hazards including earthquakes, floods, windstorms, and droughts remains inadequately investigated. Moreover, current digital twin frameworks are generally tailored to specific infrastructure types, limiting their applicability across diverse urban infrastructure systems.

## 3. Research Methodology

This study uses a research approach that includes quantitative analysis and simulations to create a resilient building design with an IoT-enabled SHM system.

### 3.1. Hazard Identification and Assessment

#### ➤ Earthquake Hazard Assessment

Earthquakes is one of the most destructive Natural Hazard that causes severe damage in building structures because of ground shaking, lateral forces and dynamic vibrations. In this study, seismic hazard assessment is carried out to help to understand the response of structure under earthquake loading conditions for the proposed building. The assessment is based on seismic zonation maps, geological surveys and national building design codes, and the seismic intensity at the selected site is determined. Parameters taken into account are Peak Ground Acceleration (PGA), response spectrum data, soil parameters and seismic zone factors.

PGA is the highest acceleration that the ground undergoes during an earthquake, and it's a key measure of earthquake intensity. The response spectrum represents the maximum response of the structures having different natural frequencies when excited by the earthquake. Seismic wave amplification is very much dependent on the type of soil, and in general the responses of the structures are larger for soft soils than for hard rock, especially in the vicinity of coastal areas and on deltaic deposits. The seismic zone factor is a measure of the seismicity level in a specific geographical area which directly relates to design forces.

#### ➤ Wind Hazard Assessment

Wind loading is an important design factor for medium or high-rise structures in that strong winds can create high lateral forces and dynamic effects that affect structural stability and comfort to the occupants. Wind hazard assessment is the process of determining the forces and behaviors of the wind acting on the building envelope and structural system. The assessment is made using meteorological data, regional wind maps, terrain and building geometry.

Wind loads are affected by various factors such as the fundamental wind speed, terrain category, building height, topography, and exposure. The basic wind speed is the highest wind velocity that can be expected in a particular area. Terrain roughens cause changes in the wind flow pattern and in the intensity of turbulence, and building height affects the distribution of wind pressure as wind velocity typically increases with height above ground level.

#### ➤ Flood Hazard Assessment

Flooding is one of the most common natural hazards, and the most economically harmful, especially in urban and coastal areas. The loss of building foundations, structural components, utility services and/or occupants are all potential negative impacts of flood hazards. Hence flood hazard mapping is performed to find the likelihood of a proposed structure to be affected by flood hazards and to formulate suitable mitigation strategies.

Key flood parameters such as flood depth, flood velocity, flood duration, hydrostatic pressure and hydrodynamic forces are taken into account. The depth of flood water will dictate the degree of inundation around the structure and the velocity of the water will impact the erosion and scouring around a foundation. Flood duration is a factor in deterioration of materials and long-term degradation of structure.

### 3.2. Building Model Development

A G+10 RC building is chosen as the case study structure for assessing the framework of proposed IoT-based multi-hazard resilient design. M30 concrete and Fe500 reinforcement steel are used to obtain required strength, durability and ductility. Full building model is developed with Building Information Modeling (BIM) and Finite Element Analysis (FEA) software, allowing 3D viewing, structural simulation, load applied, behavior of the building under earthquake, wind and flood hazards to determine the overall response. IoT sensors are integrated within the BIM model to enable the real-time structural health monitoring and the building's resilience analysis.

**Table 1: Building Specifications**

Parameter	Specification
Building Type	Reinforced Concrete (RC) Residential Building
Number of Floors	G+10
Total Floors	11
Floor Height	3.2 m
Total Building Height	35.2 m
Concrete Grade	M30
Reinforcement Steel	Fe500



Figure 3: Proposed G+10 IoT-Based Multi-Hazard Resilient Building

### 3.3. IoT-Based Structural Health Monitoring (SHM) System

The proposed multi-hazard resilient building framework is composed of the IoT-Based SHM system. The main goal of the SHM system is to monitor the structural condition of the building continuously and to provide real time information about the buildings performance in earthquake, wind and flood hazard.

Table 1: Smart Sensor Types and Functions

Sensor Type	Purpose
Accelerometer	Earthquake Monitoring
Strain Gauge	Structural Stress Monitoring
Displacement Sensor	Drift Measurement
Inclinometer	Building Tilt Monitoring
Water-Level Sensor	Flood Detection
Temperature Sensor	Environmental Monitoring

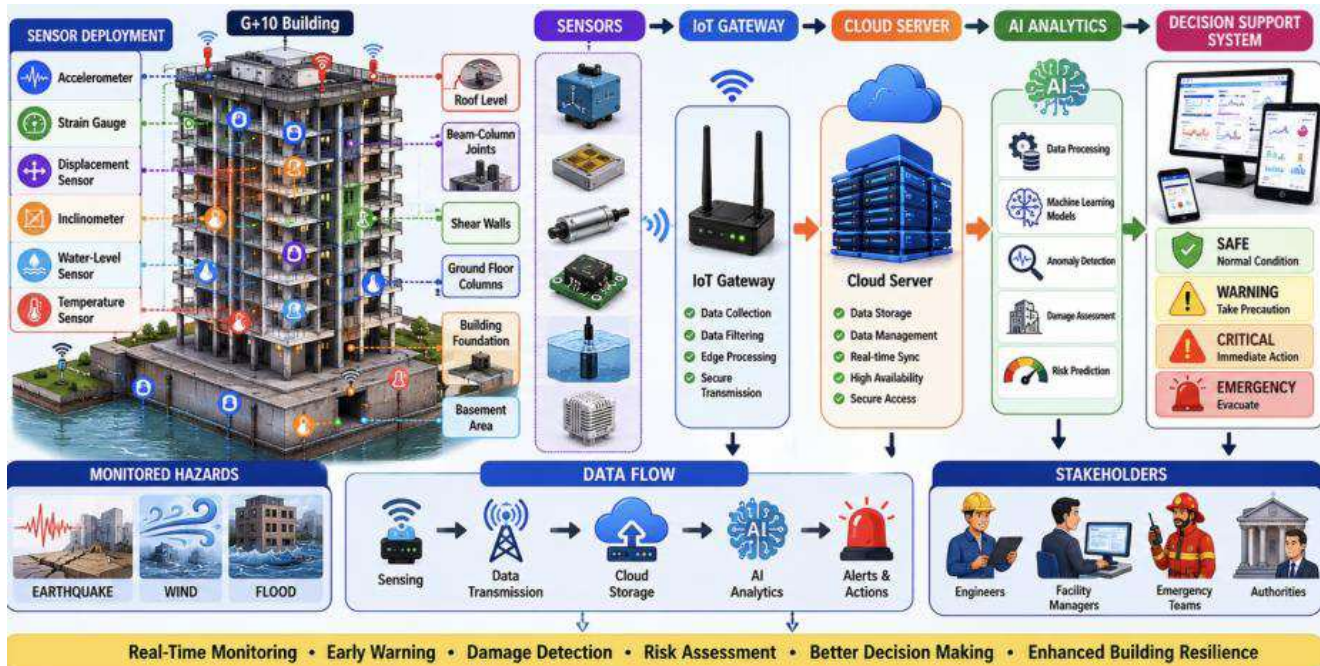


Figure 4: IoT sensor

The first level is a continuous measurement of structural and environmental information by sensors. These data are sent wirelessly via an IoT gateway acting as a communication interface between field devices and cloud infrastructure. Depending on the monitoring needs and range, communication technologies like Wi-Fi, or 5G networks can be used. The cloud server is able to store massive amounts of data from the sensor, and offers scalable computation resources for data processing.

The algorithms of Artificial Intelligence (AI) and Machine Learning (ML) analyse incoming data streams to detect anomalies, identify damage patterns, predict structural deterioration and hazard severity levels. The final phase is the Decision Support System (DSS) which translates the analytical results into information that can be

used by engineers, facility managers and emergency response teams. The system notifies of warnings and emergency notifications automatically as soon as the sensor values are above the set safety limits via mobile application, web dashboard, SMS notifier or e-mail service.



**Figure 5: IoT architecture Framework**

### 3.4. CNN–LSTM Hybrid Deep Learning Model

A CNN-LSTM hybrid network has been used in the proposed IoT-based SHM system for intelligent detection of structural damages along with providing an early warning. It is capable of processing a huge amount of real-time data obtained from a number of different sensors such as accelerometers, strain gauges, displacement sensors, inclinometers, water level sensors, and temperature sensors deployed across the entire structure. As the data obtained for structural health monitoring includes both spatial information as well as temporal information, the use of CNN-LSTM can be a good choice in this scenario.

The input data from sensors is in the form of a multivariate time series:

$$X = [x_1, x_2, x_3, \dots, x_n]$$

Where  $x_i$  represent the measured structural response at the instant time  $i$ . The CNN layer first attempts to extract discriminative features from the raw sensor signals via convolution operation. Mathematically, the convolution layer can be formulated as follows:

$$F_k = \sigma(W_k * X + b_k)$$

Where  $F_k$  is the extracted feature map,  $W_k$  is the convolution kernel,  $b_k$  is the bias term, and  $\sigma$  is the activation function. The features then undergo the pooling operation for dimensional reduction, computation reduction, and structural information preservation.

The obtained features then feed into the LSTM network, which models the long-term dependencies in structural responses. The LSTM network comprises the forget, input and output gates, which control the flow of information within the LSTM. These gates are defined as:

$$f_t = \sigma(W_f[h_{t-1}, x_t] + b_f)$$

$$i_t = \sigma(W_i[h_{t-1}, x_t] + b_i)$$

$$o_t = \sigma(W_o[h_{t-1}, x_t] + b_o)$$

The cell state update is given by:

$$C_t = f_t C_{t-1} + i_t \tilde{C}$$

and the hidden state is computed as:

$$h_t = o_t \tanh(C_t)$$

These equations help the network to store critical historical data while deleting any unnecessary information. Therefore, the structure learns behavior patterns when subjected to earthquake, wind, and flooding loads.

The last step is determining the condition of the structural health using the fully connected layer and the Softmax classifier:

$$P(y_i) = \frac{e^{z_i}}{\sum_{j=1}^n e^{z_j}}$$

Where  $P(y_i)$  is the probability of  $i^{th}$  class. The categories of the output include Safe, Warning, Critical, and Emergency. The CNN-LSTM network makes high-quality predictions about structural damages, detection of anomalies, and assessment of the risk factor, which makes it a reliable choice to increase the resistance of buildings.

### 3.5. Performance Evaluation Metrics

For verification of model researchers use following performance measures:

$$\text{Resilience Index (RI)} = \frac{P_r}{P_o}$$

$$\text{Accuracy} = \frac{TN+TP}{FP+TN+TP+FN} \tag{8}$$

$$\text{Recall} = \text{Sensitivity} = \frac{TP}{TP+FN} \tag{9}$$

$$\text{Precision} = \frac{TP}{FP+TP} \tag{10}$$

$$\text{F1 - score} = \frac{2 * P * R}{P + R} \tag{11}$$

## 4. Result and Discussion

### 4.1. Structural Performance of Hazards

The results of the earthquake performance presented show the effectiveness of the proposed IoT-based resilient building compared to the conventional building under the seismic loading condition. The proposed model achieved a reduction of about 31.69% in the maximum displacement when compared with the conventional model, which was 82.45 mm. Likewise, the story drift ratio was reduced from 1.92% to 1.21%, which indicates that the lateral stability of the structure has improved and the deformation of the story during earthquake events has decreased. The base shear was slightly reduced from 4250kN to 4125kN, indicating better load distribution and structural efficiency. In addition, structural damage index was reduced from 0.36 to 0.18, which was almost 50% reduction in the chances of damage. Over most importantly, the resilience index rose from 0.71 to 0.89, suggesting a stronger recovery ability, structural strength, and seismic resilience of the proposed IoT enabled building framework.

**Table 3: Earthquake Performance Results**

Parameter	Conventional Building	Proposed IoT-Based Building
Maximum Displacement (mm)	82.45	56.32
Story Drift Ratio (%)	1.92	1.21
Base Shear (kN)	4250	4125
Structural Damage Index	0.36	0.18
Resilience Index	0.71	0.89

The wind resistance results indicate that the proposed IoT-based building exhibits significantly better performance than the conventional building under strong wind loading conditions. The roof displacement was reduced from 64.87 mm to 43.51 mm, a reduction of about 32.93%, implying that the structural stability and lateral stiffness were improved. Likewise, the maximum story drift ratio decreased from 1.35% to 0.89%, which showed its resistance to wind-induced deformation. This wind-induced acceleration was reduced from 0.42 m/s<sup>2</sup> to 0.25 m/s<sup>2</sup>, which represents a gain of almost 40.48% for the comfort of the occupants and vibration control. In addition, the structural stress was lowered from 18.75 MPa to 13.28 MPa, which indicates a decrease in the stress concentration in critical structure parts. The resilience index value rose from 0.76 to 0.91, indicating the high adaptability, recovery capability and overall wind resistance of the proposed structural monitoring framework with the IoT technology.

**Table 4: Wind Resistance Results**

Parameter	Conventional Building	Proposed IoT-Based Building
Roof Displacement (mm)	64.87	43.51
Maximum Story Drift (%)	1.35	0.89
Wind-Induced Acceleration (m/s <sup>2</sup> )	0.42	0.25
Structural Stress (MPa)	18.75	13.28
Resilience Index	0.76	0.91

The outcomes of the flood resistance clearly show the effectiveness of the proposed IoT based resilient building in mitigating the damage caused by floods. The settlement of the foundation in the conventional building was 24.62 mm, and in the proposed building it was 14.37 mm, representing a reduction of approximately 41.63%. It shows that the settlement of the proposed structure will be less during flood conditions, which will provide better stability of the foundation. In the same way, the quantity of water ingress dropped drastically from 18.4 m<sup>3</sup> to 6.2 m<sup>3</sup> which shows a reduction of almost 66.30%, thus reducing damage to structural and non- structural components. The damage index for the structure was lowered from 0.29 to 0.11, which indicates a significant decrease in exposure to flood effects. In addition, the recovery time was reduced from 18 days to 8 days, suggesting improved recovery in terms of functionality of the buildings after a flood event. The resilience index also rose significantly from 0.73 to 0.93, which shows the high level of resilience, recovery and overall performance of the proposed IoT-based monitoring and protection system.

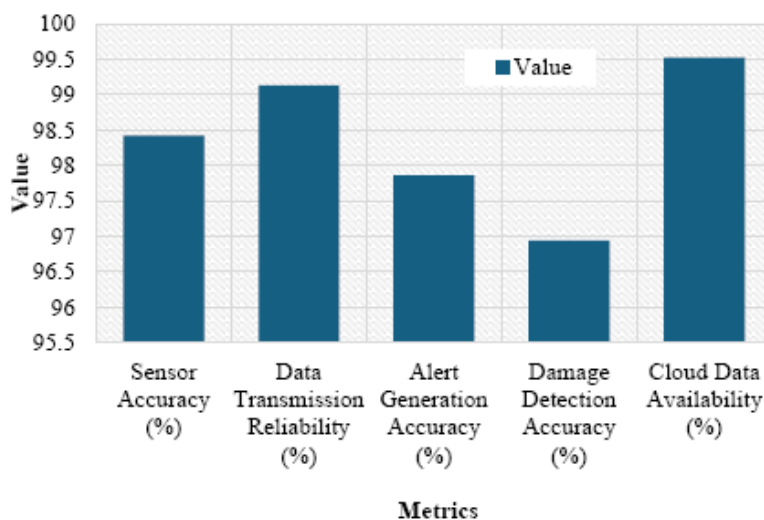
**Table 5: Flood Resistance Results**

Parameter	Conventional Building	Proposed IoT-Based Building
Foundation Settlement (mm)	24.62	14.37
Water Ingress Volume (m <sup>3</sup> )	18.4	6.2
Structural Damage Index	0.29	0.11
Recovery Time (Days)	18	8
Resilience Index	0.73	0.93

#### 4.2. IoT-Based Structural Health Monitoring Result

The performance results of the IoT monitoring indicated that the presented SHM framework can effectively and reliably be used for real-time evaluation of a building. The measured results include: sensor accuracy of 98.42%, which demonstrates the high degree of correctness in measuring environmental and structural quantities, data transmission reliability of 99.13% in establishing a stable and robust communication link between sensors, gateway, and the cloud server, and the alert generation accuracy of 97.86%, which verifies that the system correctly triggers and issues an alarm when a critical structural health condition occurs.

The accuracy of damage detection stood at 96.94%, proving the reliability of CNN-LSTM in detecting anomalies in the structures. The average response time of 2.14 seconds confirms quick processing and decision-making abilities. In addition, the cloud data availability of 99.52% indicates that the data will be available all the time. Therefore, these findings confirm the reliability, efficiency, and ability to work in real time of the IoT-based building monitoring system for multi-hazard resilient buildings.

**Figure 6: Graph of IoT Monitoring Performance**

### 4.3. AI-Based Damage Prediction Results

The performance results of the proposed AI model show that the structural damage detection and classification process in the multi-hazard environment is effective by using the CNN–LSTM hybrid framework. The model showed high accuracy of 97.84%, which means that the model has good prediction capability. The model's accuracy in detecting structural damage, with a precision of 97.51%, ensures that it only generates a few false alarms, whereas its recall of 97.22% guarantees that it does not miss out on a significant number of actual damage cases. The F1-score is 97.36%, indicating a well-balanced performance between precision and recall. Moreover, the results of the ROC-AUC analysis show excellent classification performance and good discrimination among structural health conditions, further validating the robustness and reliability of the proposed AI-based monitoring system.

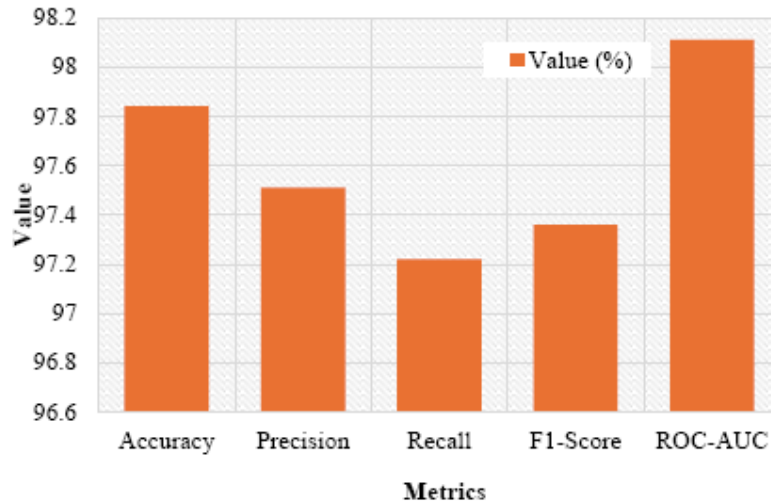


Figure 7: Graph of AI model performance

### 4.4. Early Warning System Performance

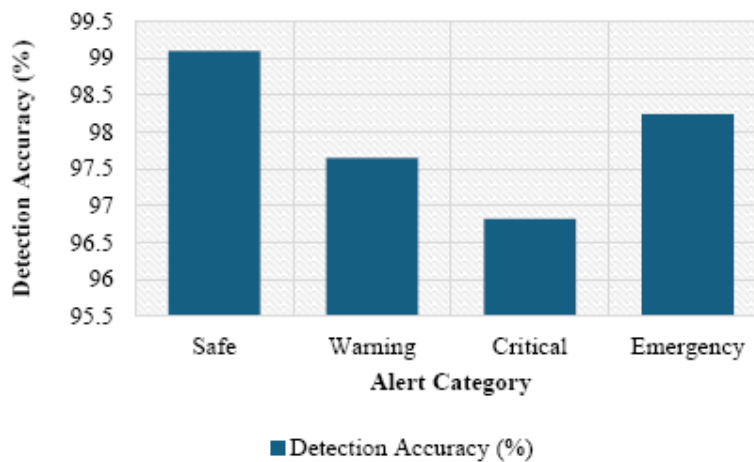
Figure 8 shows the performance of the IoT-based Early Warning System that has been proposed and is incorporated into the SHM system.



Figure 8: Early warning system performance

The dashboard monitors the critical structural and environmental factors in real time such as acceleration, strain, displacement, tilt angle, water level, and temperature. It was observed that the average response time of the system was 2.14 seconds, which allowed quick detection and notification about any abnormality in the structure. 24 sensors were working on the building, and the performance of the system was up to 98.7%.

The warning panel was able to detect the presence of excessive displacement, which was 2.38 mm on the 6<sup>th</sup> floor level. In the same manner, alerts for changes in tilt angle values and increase in water levels in the basement area were detected correctly and presented through the interface. From the sensor status panel, we can see that out of the total sensors installed, 17 were functioning normally without any abnormal condition. Meanwhile, only a few were flagged as warnings or critical sensors. Through such a system, engineers and building administrators will be able to immediately act based on the information presented, thus preventing any possible danger in the building. These results demonstrate that the proposed early warning system provides accurate monitoring, rapid alert generation, and effective decision support, thereby enhancing the overall resilience and safety of the building under multi-hazard conditions. The warning mechanism used in this case accurately categorized hazard statuses and issued notifications accordingly to the building's administrators. The average percentage of the alert classifications was 97.95%, supporting proactive risk management.



**Figure 9: Graph of alert classification results**

## 5. Conclusion

A multi-hazard (earthquake, wind, flood) resilient building design framework for improved building performance was successfully developed and verified by employing smart engineering techniques with IoT-based Structural Health Monitoring (SHM) and a CNN-LSTM-based damage prediction model. Quantitative simulation-based approach with a G+10 Reinforced Concrete (RC) building model, finite element analysis, hazard evaluation techniques, real-time sensor integration and artificial intelligence-based monitoring, yielded a great improvement in building performance as opposed to a conventional building. For earthquake loading, reduction in the peak displacement was noted as 31.69% and the damage index reduced from 0.36 to 0.18. For wind hazard, the peak displacement at roof was reduced by 32.93% and the wind induced acceleration decreased by 40.48%. The peak settlement of the foundation was decreased by 41.63% and the volume of water ingress was minimized by 66.30% during flood hazard. The reliability of the developed IoT-SHM system in terms of sensor reading was found to be 98.42%, transmission was reliable with 99.13% and

alerts were generated with 97.86% accuracy. Moreover, prediction model (CNN-LSTM) developed for damage estimation recorded 97.84% accuracy for structural damage estimation.

## Reference

- [1] Sreekeasha, K. S., Sreevalsa Kolathayar, and N. Vinod Chandra Menon. "Civil Engineering for Multi-hazard Risk Reduction-An Introduction." In *International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development*, pp. 1-10. Singapore: Springer Nature Singapore, 2023.
- [2] Bianchi, Simona. "Integrating resilience in the multi-hazard sustainable design of buildings." *Disaster Prevention and Resilience* 2, no. 3 (2023): N-A.
- [3] Mohammed, Hussam Ali, and Hussein Alaa. "Performance Evaluation of Reinforced Concrete Structures Under Multi-Hazard Natural Disaster Scenarios."
- [4] Mavisclara, Ohaka Amarachi, Ibrahim Isiaka Oshobugie, Atoyebi Temitope Olufunmi,

- Suleiman Mustapha, Adeyinka Taslim Olabode, Ozuruoha Nkiruka Esther, and Oyeboade Adekunle Yakub. "Engineering Resilience: Harnessing Smart Technologies for Climate-Proof Infrastructure." *World Journal of Advanced Engineering Technology and Sciences-(WJAETS)* 17, no. 01 (2025): 356-369.
- [5] Roy, Tathagata, and Vasant Matsagar. "Multi-hazard analysis and design guidelines." *Current Science* 121, no. 1 (2021): 44-55.
- [6] Okem, Eche Samuel, Zamathula Queen Sikhakhane Nwokediegwu, Aniekan Akpan Umoh, P. W. Biu, B. O. Obaedo, and M. Sibanda. "Civil engineering and disaster resilience: A review of innovations in building safe and sustainable communities." *International Journal of Science and Research Archive* 11, no. 1 (2024): 639-650.
- [7] Adejumobi, Adeyemi Michael. "CONSTRUCTING BIM-DRIVEN MULTI-HAZARD RESILIENCE INDICES COMBINING CLIMATE-STRESS SCENARIOS WITH SUSTAINABILITY-WEIGHTED CONSTRUCTION DECISION OPTIMIZATION TECHNIQUES." *International Journal Of Engineering Technology Research & Management (IJETRM)* 9, no. 12 (2025): 163-176.
- [8] Jami, Matin, Rajesh Rupakhety, Said Elias, Bjarni Bessason, and Jonas Th Snæbjörnsson. "Recent advancement in assessment and control of structures under multi-hazard." *Applied Sciences* 12, no. 10 (2022): 5118.
- [9] Flint, M., S. L. N. Dhulipala, Y. Shahtaheri, H. Tahir, T. Ladipo, M. R. Eatherton, J. L. Irish et al. "Developing a decision framework for multi-hazard design of resilient, sustainable buildings." In *1st Int. Conf. on Natural Hazards and Infrastructure (ICONHIC2016)*. 2016.
- [10] Bakhtiari, Soheil. "Multi-hazard risk assessment of the interconnected infrastructure systems." PhD diss., The University of Western Ontario (Canada), 2024.
- [11] Saikat, Monowar Hossain, Md Shoag, Elma Akter, and Joy Chandra Bormon. "Seismic and Climate-Resilient Infrastructure Design for Coastal and Urban Regions." *Authorea Preprints* (2025).
- [12] Ba, Rui, Qing Deng, Yi Liu, Rui Yang, and Hui Zhang. "Multi-hazard disaster scenario method and emergency management for urban resilience by integrating experiment-simulation-field data." *Journal of Safety Science and Resilience* 2, no. 2 (2021): 77-89.
- [13] Jami, Abdul Matin. "Multi-Hazard Assessment of Long-Span Bridges, Considering the Effects of Seismic and Wind Action." (2025).
- [14] Qi, Xiaoqing, Huaichao Wang, Xiaoyu Xiong, Anqi Zhou, Qing Sun, and Qiang Zhang. "Digital Twin Framework for Structural Health Monitoring of Transmission Towers: Integrating BIM, IoT and FEM for Wind-Flood Multi-Hazard Simulation." *Applied Sciences* 16, no. 8 (2026): 3620.
- [16] Dilmen, Ömer, Abdullah Demir, Şevki Öztürk, Volkan Kalpakçı, and Ali Ersin Dinçer. "A machine-learning-based multi-hazard GIS-AHP framework for wind turbine siting under earthquake-landslide coupling." *Environmental Research Communications* (2026).
- [17] Rahimi, Maryam. "A Multi-Hazard Digital Twin Framework for Integrated Structural Health Monitoring of Urban Infrastructure under Seismic and Flood Risks: A Case Study of Tehran." (2025).
- [18] Ugliotti, Francesca Maria, Muhammad Daud, and Emmanuele Iacono. "Spatial Insights for Building Resilience: The Territorial Risk Management & Analysis Across Scale Framework for Bridging Scales in Multi-Hazard Assessment." *Smart Cities* 8, no. 1 (2025): 27.
- [19] Ugliotti, Francesca Maria, Muhammad Daud, and Emmanuele Iacono. "Spatial Insights for Building Resilience: the TERIMAAS Framework for Bridging Scales in Multi-Hazard Assessment." (2024).
- [20] Faraji, Farzad. "AI-Integrated Structural Health Monitoring for Multi-Hazard Resilience in Urban Infrastructure: A Case Study of Tehran's Water and Flood Management Systems." Unpublished manuscript.
- [21] Esmailzadeh, Abdulsalam, Mahmoud Arvin, Mohammad Ebrahimi, Mohammad Kazemi Garajeh, and Zahra Afzali Goruh. "Measuring livelihood resilience in multi-hazard regions: A case study of the khuzestan province in the persian gulf coast." *Earth* 5, no. 4 (2024): 1052-1079.