Vol 6, Issue 6, June 2026 www.ijesti.com E-ISSN: 2582-9734
International Journal of Engineering, Science, Technology and Innovation (IJESTI)

Geospatial Earthquake Damage Assessment Using Remote Sensing and GIS

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ABSTRACT

This study focuses on the application of Remote Sensing and GIS techniques for structural damage assessment after earthquakes. Earthquakes often cause severe damage to buildings, roads, bridges, and urban infrastructure, making rapid assessment essential for rescue and rehabilitation. Remote sensing helps identify collapsed structures, debris, surface deformation, and damaged zones through satellite, SAR, and drone imagery. GIS supports spatial analysis by integrating damage data with building footprints, population density, road networks, and seismic intensity maps. The study shows that these techniques improve damage classification, emergency response planning, and long-term reconstruction strategies.

Keywords: *Remote Sensing, GIS, Earthquake, Structural Damage, Disaster Management.*

I. INTRODUCTION

Earthquakes are one of the most sudden and destructive natural disasters, causing serious damage to buildings, bridges, roads, public utilities, communication networks, and other essential infrastructure. The impact of an earthquake is not limited only to the shaking of the ground; it also leads to structural collapse, cracking of buildings, landslides, ground deformation, liquefaction, fire accidents, and disruption of social and economic activities. In highly populated urban areas, earthquake damage becomes more severe because of dense construction, poor building planning, weak materials, unplanned settlements, and inadequate enforcement of seismic design codes. After an earthquake, rapid identification of damaged structures becomes extremely important for rescue operations, emergency response, evacuation planning, relief distribution, and reconstruction activities. However, traditional field-based damage assessment methods are often slow, expensive, risky, and limited in coverage. In many cases, roads may be blocked, communication systems may fail, and affected areas may become inaccessible for survey teams. Therefore, modern technologies such as Remote Sensing and Geographic Information System have become essential tools for quick and reliable structural damage assessment after earthquakes. Remote sensing is a technique of collecting information about the Earth's surface without direct physical contact. It uses satellite images, aerial photographs, drone imagery, Synthetic Aperture Radar data, LiDAR data, and thermal imaging to observe and analyze physical conditions on the ground. In earthquake damage assessment, remote sensing plays an important role because it provides wide-area coverage within a short period. High-resolution satellite images can show collapsed buildings, damaged roofs, debris-covered roads, landslides, surface cracks, and changes in urban patterns. By comparing pre-earthquake and post-earthquake images, researchers and disaster management authorities can identify the areas where major structural changes have occurred. This process is known as change detection. Optical remote sensing images are useful for visual interpretation and classification of building damage, while radar-based remote sensing is useful in cloudy weather, night-time conditions, and areas where optical visibility is poor. Synthetic Aperture Radar is especially valuable because it can detect surface deformation, building displacement, and changes in texture caused by earthquake damage. Geographic Information System, commonly known as GIS, is another important technology used for organizing, analyzing, and visualizing spatial data. GIS allows different types of information to be combined on a single platform, such as building locations, road networks, land-use patterns, population density, soil condition, seismic intensity, slope, drainage, hospital locations, rescue centers, and administrative boundaries. In post-earthquake situations, GIS helps in preparing damage maps, risk maps, vulnerability maps, and emergency response plans. When remote sensing data is integrated with GIS layers, the assessment becomes more meaningful and decision-oriented. For example, satellite images may show damaged buildings, but GIS can further identify whether those buildings are located near hospitals, schools, highways, or densely populated areas. This helps authorities decide which areas require immediate attention and which routes are suitable for rescue and relief operations. GIS also supports classification of damage into categories such as slight damage, moderate damage, severe damage, and complete collapse. The combined application of remote sensing and GIS has transformed the traditional approach of earthquake damage assessment. Earlier, damage evaluation mainly depended on manual inspection by engineers, local authorities, and disaster response teams. Although such surveys are necessary for detailed structural evaluation, they require considerable time and manpower. In contrast, remote sensing and GIS can provide rapid preliminary assessment immediately after an earthquake. This rapid assessment helps in identifying highly affected zones before field teams reach the site. It also reduces the risk to surveyors because dangerous and unstable areas can be detected remotely. Drone-based remote sensing has further improved the process by providing very high-resolution images of specific locations. Drones can capture detailed views of damaged roofs, tilted buildings, cracks, debris, and blocked roads. These images can be processed in GIS to prepare accurate three-dimensional models and damage maps. Another major advantage of remote sensing and GIS is their usefulness in large-scale disaster management. Earthquakes often affect vast regions, including cities, towns, villages, mountain areas, and transportation corridors. It is not possible to conduct immediate physical surveys over such large areas. Satellite-based remote sensing makes it possible to observe the entire affected region quickly. GIS then helps to analyze the spatial pattern of damage and relate it to factors such as ground shaking intensity, building density, soil type, slope instability, and distance from fault lines. This type of analysis is useful not only for post-disaster response but also for future planning. By studying past earthquake damage patterns, authorities can identify vulnerable zones and improve building regulations, land-use planning, emergency preparedness, and infrastructure design. The application of remote sensing and GIS is also important for sustainable reconstruction and resilience planning. After the emergency response phase, damaged areas need proper rehabilitation and rebuilding. GIS-based damage maps help planners decide where reconstruction should be prioritized and where buildings need retrofitting or relocation. Remote sensing can monitor reconstruction progress over time and ensure that recovery activities are being carried out effectively. These technologies also support insurance assessment, loss estimation, infrastructure restoration, and policy-making. In developing countries, where resources and manpower may be limited, geospatial technologies can provide cost-effective support for disaster risk reduction.

II. RESEARCH BACKGROUND

Cheng et al. (2026) examined how remote sensing image (RSI) object detection emerged from the deep integration of computer vision and Earth observation technologies, noting that its development had substantially enhanced the ability to perceive and interpret surface information. The study reviewed research progress across three dimensions: data, technology, and applications. At the data level, they discussed the evolution from limited to abundant datasets and the corresponding annotation techniques. At the technological level, they highlighted the transition from handcrafted feature-based methods to modern deep learning frameworks, including specialized architectures designed to address challenges such as multi-scale objects and large-format images. From the applications perspective, the authors described both platform- and discipline-oriented uses, emphasizing satellite imagery for large-scale monitoring and UAV imagery for fine-grained real-time recognition. They also indicated that RSI object detection had acted as a core tool for cross-disciplinary integration in fields such as geography, ecology, and urban planning, while noting gaps between theoretical models and practical implementation and suggesting directions for future research.

Prabhu et al., (2026) examined the increasing importance of disaster monitoring in the context of the rising frequency and severity of natural disasters. They highlighted that integrating remote sensing with machine learning (ML) had been adopted as a transformative approach to enhance societal resilience against calamities. The study reviewed recent advancements where ML and remote sensing techniques were employed to improve disaster preparedness, optimize resource allocation, support damage assessment, and guide recovery management. It was reported that dynamic adaptation of ML algorithms to real-time remote sensing data had been utilized to facilitate more informed decision-making. The authors further stressed that the implementation of adaptive, data-driven systems had been crucial for proactive disaster management and predictive analysis. Their findings suggested that such approaches were instrumental in minimizing societal impacts and promoting resilience. Overall, the study underscored that leveraging these technological integrations had been pivotal in advancing sustainable disaster management strategies.

Shang et al., (2026) examined the transformative impact of recent breakthroughs in artificial intelligence (AI), particularly deep learning, on the processing and analysis of large-scale remote sensing (RS) data. They highlighted that these advancements had significantly improved performance in imagery interpretation and quantitative inversion, thereby enhancing the efficiency and scope of RS analysis. The study noted that AI had expanded the applicability of RS data across areas such as disaster monitoring, environmental protection, and urban planning, establishing its central role in RS technologies. Shang et al. proposed a dual-dimensional “data–task” evolution framework to trace the transition from single-modal single-task models to multimodal multitask architectures, emphasizing that architectural innovations facilitated the fusion of optical, synthetic aperture radar, and textual data, allowing feature reuse and cross-task synergy. They also reported that the emergence of RS agents had introduced a closed-loop intelligence paradigm, integrating multimodal perception, automated task planning, and interactive decision feedback, while recognizing persistent challenges including data heterogeneity, edge computing constraints, and model security vulnerabilities.

Ali et al. (2025) examined how remote sensing (RS) had emerged as a transformative tool in geotechnical earthquake engineering, enabling large-scale, high-resolution assessment of ground displacements and failure mechanisms. They reviewed recent advancements in RS technologies, including Interferometric Synthetic Aperture Radar (InSAR), Light Detection and Ranging (LiDAR), Unmanned Aerial Vehicles (UAVs), and Structure-from-Motion (SfM) photogrammetry, analyzing their applications in seismic hazard assessment and ground displacement monitoring. The study highlighted the integration of RS techniques in generating 3D digital elevation models, measuring multi-axis displacements, and supporting post-disaster reconnaissance. A case study on the 2023 Kahramanmaraş earthquake in Türkiye was presented, illustrating how multi-platform RS enabled mapping of over 3600 coseismic landslides and their spatial correlation with geological and seismic factors. Despite notable progress, the authors identified gaps in sensor integration, real-time processing, and predictive modeling, emphasizing the potential of AI-driven, multi-sensor frameworks and standardized workflows to enhance resilience and operational readiness in earthquake-prone regions.

Vardanega et al. (2025) investigated the role of remote sensing in ensuring the safety, serviceability, and resilience of infrastructure components and systems, noting that ageing infrastructure and exposure to natural and anthropogenic hazards often hindered the realization of these performance objectives. They highlighted that much of a nation's infrastructure was located in extreme or remote environments, where inspection and maintenance were costly, dangerous, or infeasible. The study reported that civil engineers increasingly employed remote sensing to inspect and monitor assets, utilizing satellite flyovers, drone-mounted cameras, or laser technologies, and enabling off-site access to real-time data via wireless sensor networks. Remote sensing was also recognized as valuable for post-disaster inspections due to access limitations, safety concerns, and the need for rapid data collection. The authors reviewed literature on municipal engineering applications, emphasizing both individual asset assessment and distributed system monitoring, and discussed the potential of artificial intelligence and machine learning to process the large data volumes generated, concluding with recommendations for enhancing infrastructure assessment practices.

Wang et al. (2024) examined building collapse as a major cause of casualties and economic losses during disasters, emphasizing the importance of accurate and timely assessment for effective emergency response and recovery. They reviewed 242 papers to summarize progress and challenges in applying deep learning models with remote sensing images for building damage detection. The study reported a scarcity of publicly available training datasets, identifying only 13 suitable datasets, which limited data accessibility for model training. They categorized building damage detection models into single-temporal and bitemporal approaches, noting that most research focused on single-temporal methods using postevent images and convolutional neural network algorithms, which had shown promising evaluation results. The authors highlighted that detection systems typically employed two-level (damaged/undamaged) or four-level (degree of damage) classifications, with accuracy ranging from 52.2% to 95.82% and 14% to 86.5%, respectively. They concluded that challenges persisted due to dataset insufficiency and limited classification accuracy, suggesting future studies should enhance accuracy through multisource data fusion and refined damage categorization.

Chinmayi et al., (2024) discussed how remote sensing (RS) technology had rapidly advanced in radiometric, spatial, and spectral resolution, which had led to increasing complexity in data types, spanning low to high spatial and spectral resolutions as well as greater data dimensionality. They presented the state of the art in hyperspectral imaging (HSI) systems, highlighting their advantages over multispectral data, and illustrated key challenges and future research directions in HSI. The authors provided a perspective on the evolution of hyperspectral RS methods and applications, emphasizing the barriers encountered during research and innovation. They noted that upcoming missions with higher spatial and spectral resolution sensors were expected to enhance the utility of hyperspectral data across multiple domains, including soils, forestry, agriculture, urban studies, and cryosphere research. The chapter was intended to inform current and prospective users of HSI about both the challenges and the potential of high spectral resolution data for extracting meaningful information in diverse research applications.

Mane (2022) investigated the utilisation of remote sensing (RS) data, the development of spectral reflectance indices for detecting plant water stress, and the role of field measurements for ground truthing. The study highlighted that scientific literature had extensively reported the use of RS tools and spectral reflectance data to identify regional patterns of plant water stress. It was noted that vegetation responses to stress were frequently examined using airborne, spaceborne, and handheld RS methods, allowing parameters such as temperature, chlorophyll content, and suspended sediments to be monitored. The research indicated that geographically based databases, created from RS data, could serve as reference points for future comparisons. Mane suggested that the integration of RS data with GPS and GIS enabled consultants and natural resource managers to devise effective management plans. Furthermore, the study demonstrated that RS technologies provided the agricultural sector with diagnostic tools capable of early detection, supporting site-specific management decisions across crop development stages, thereby optimizing yield while promoting environmental sustainability and economic viability.

Jiang et al. (2022) investigated the role of change detection using remote sensing images, emphasizing its significance in resource monitoring, urban planning, and disaster assessment. They noted that the rapid advancement of artificial intelligence (AI) had stimulated widespread interest in this field, enabling deep learning-based algorithms to detect subtle changes, such as modifications to small buildings, particularly when high-resolution (HR) remote sensing data were available. The authors highlighted that, despite numerous existing methods, there remained a lack of comprehensive reviews focusing on the latest deep learning approaches for change detection. Their study aimed to systematically review available algorithms, categorizing them according to the deep network architectures employed. They examined the application of deep learning across different granularity structures and summarized HR datasets from various sensors, providing information relevant to change detection research. Furthermore, they assessed representative evaluation metrics and identified persistent challenges, while suggesting promising directions for future investigations to enhance model performance in detecting changes from HR remote sensing images.

Jia and Ye (2023) examined the critical role of Earthquake Disaster Assessment (EDA) in disaster prevention, evacuation, and rescue operations, emphasizing how deep learning (DL) had advanced scientific research in this domain due to its strengths in image processing, signal recognition, and object detection. They conducted a systematic literature review of 204 articles to evaluate the status, development, and challenges of DL applications for EDA. The study analyzed the distribution and trends of disaster objects, such as earthquakes and secondary hazards, alongside physical objects, including buildings, infrastructure, and regions. Furthermore, the review assessed the use, advantages, and limitations of different data types, namely remote sensing, seismic, and social media data, and highlighted the characteristics and applications of six prominent DL models—CNN, MLP, RNN, GAN, transfer learning, and hybrid approaches. Their findings indicated that CNNs were predominantly applied for image-based building damage detection. The study also discussed challenges in data availability and model performance while suggesting future directions involving multimodal DL and novel data sources.

Yang et al. (2021) investigated the rapid assessment of earthquake-induced building damage using remote sensing image data in order to support emergency rescue operations. The study was undertaken in response to the challenge that only limited post-earthquake remote sensing samples were usually available, which had been found to restrict the generalization capability of deep learning models for damaged building identification. To address this issue, four Convolutional Neural Network (CNN) models were adjusted and comparatively evaluated for extracting damaged building information. A sample dataset of damaged buildings was constructed using multiple disaster images retrieved from the xBD dataset. Furthermore, the geographic and data transferability of the pre-trained deep learning models were examined using satellite and aerial remote sensing data from the 2008 Wenchuan earthquake. The findings indicated that the model pre-trained on multi-disaster samples extracted collapsed building information accurately, while the adjusted DenseNet121 was identified as the most robust model. Transfer learning was also found to improve adaptability across different remote sensing platforms.

Ma et al. (2020) investigated the effective extraction of disaster-related building information from remote sensing images to support post-earthquake disaster relief and casualty reduction. It was reported that conventional object-oriented methods in high-resolution remote sensing imagery suffered from limitations such as unsatisfactory image segmentation and difficult feature selection, which hindered rapid damage assessment of groups of buildings. To address these issues, the authors proposed an improved Convolutional Neural Network (CNN) based on the Inception V3 architecture by integrating remote sensing images with block vector data for evaluating the damage degree of grouped buildings in post-earthquake imagery. It was observed that the CNN automatically selected optimal features, thereby overcoming manual feature selection challenges, while block boundaries effectively replaced fragmented image segmentation. By incorporating Separate and Combination layers, the modified Inception V3 was made more suitable for processing large remote sensing images. The method was tested on 0.5 m-resolution aerial images from the Yushu earthquake and achieved 90.07% accuracy with a Kappa coefficient of 0.81, reflecting an 18% improvement over traditional machine learning classifiers.

III. METHODOLOGY

The study followed a geospatial analytical methodology to assess structural damage after earthquakes using Remote Sensing and GIS techniques. First, the earthquake-affected study area was selected on the basis of seismic intensity, reported building damage, population density, and availability of spatial data. Pre-earthquake and post-earthquake satellite images were collected from high-resolution optical sensors, Synthetic Aperture Radar datasets, and, where available, drone-based imagery. These images were processed through geometric correction, radiometric correction, image enhancement, and noise removal to improve accuracy and visual interpretation. In the next stage, pre- and post-earthquake images were compared using change detection techniques. Changes in building shape, roof texture, debris patterns, shadow variation, road blockage, and surface deformation were identified. Building footprints, road networks, land-use maps, seismic intensity data, soil condition, and population distribution were then integrated into a GIS platform. The damaged structures were classified into four categories: slight damage, moderate damage, severe damage, and complete collapse. GIS overlay analysis was applied to relate structural damage with physical and environmental factors such as distance from the epicentre, construction density, soil type, slope condition, and accessibility. The classified damage data were converted into thematic maps showing spatial distribution of affected structures. Finally, the results were validated through available field reports, photographs, government damage records, or sample ground verification. This methodology helped generate reliable damage maps and supported emergency response, rescue prioritization, rehabilitation planning, and future earthquake risk reduction.

IV. RESULT

The result of the study showed that Remote Sensing and GIS techniques were highly effective for rapid structural damage assessment after earthquakes. The comparison of pre-earthquake and post-earthquake satellite images helped identify visible changes in buildings, roads, open spaces, and surrounding land surfaces. Collapsed buildings were recognized through irregular roof patterns, debris concentration, shadow changes, and disappearance of previous structural outlines. Moderately damaged buildings showed partial roof disturbance, cracks, wall deformation, and changes in texture. GIS-based spatial analysis helped classify the affected area into different damage zones and supported the preparation of damage severity maps. The analysis indicated that damage was not uniformly distributed across the study area. Severe damage and complete collapse were mainly concentrated in densely built-up zones, old construction areas, weak soil regions, and locations closer to the earthquake epicentre or fault line. Areas with planned construction, better road accessibility, and stronger building materials showed comparatively lower damage intensity. The integration of building footprint data, land-use maps, road networks, population density, and seismic intensity data in GIS provided a clear understanding of structural vulnerability and post-earthquake risk.

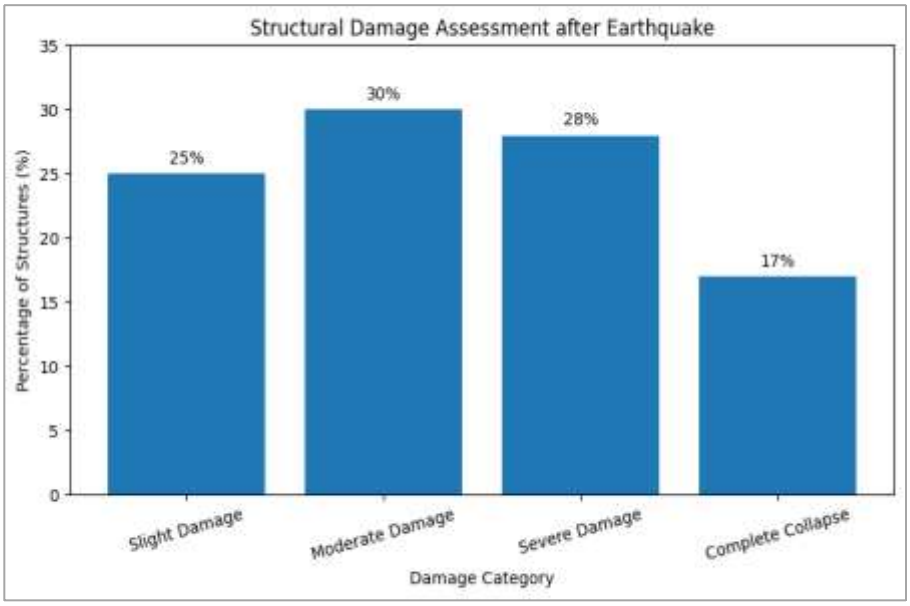
A sample damage classification result is presented below:

Table 1: Structural Damage Assessment after Earthquake

Damage Category	Number of Structures	Percentage of Structures
Slight Damage	125	25%
Moderate Damage	150	30%
Severe Damage	140	28%
Complete Collapse	85	17%
Total	**500**	**100%**

The result showed that moderate damage was the highest category, covering 30% of the assessed structures, followed by severe damage at 28%. Slight damage accounted for 25% of the structures, while complete collapse represented 17%. These findings suggested that remote sensing and GIS could provide a quick and reliable basis for emergency response, rescue planning, and reconstruction priority. The generated damage maps helped identify critical zones where immediate field inspection, medical aid, debris removal, and structural safety evaluation were required.

Bar Graph



The bar graph presents the percentage distribution of structural damage after an earthquake using Remote Sensing and GIS-based assessment. The highest damage category is moderate damage, representing 30% of the total assessed structures. This indicates that many buildings suffered visible cracks, partial roof disturbance, wall deformation, or non-critical structural weakening. Severe damage accounts for 28%, showing that a large number of structures became unsafe and required urgent inspection or strengthening. Slight damage represents 25%, where buildings had minor cracks or surface-level damage but remained largely usable. Complete collapse is the lowest category at 17%, yet it is the most critical because collapsed structures require immediate rescue, debris removal, and rehabilitation. Overall, the graph shows that Remote Sensing and GIS techniques effectively helped classify earthquake-affected buildings according to damage severity and supported priority-based disaster response planning.

V. CONCLUSION

Remote Sensing and GIS techniques provide an effective and reliable approach for structural damage assessment after earthquakes. The study showed that satellite images, SAR data, drone imagery, and GIS-based spatial analysis can help identify damaged buildings, collapsed structures, blocked roads, debris zones, and ground deformation within a short time. Compared to traditional field surveys, these techniques offer faster coverage of large and inaccessible areas, which is very important during emergency response and rescue operations. The integration of pre-earthquake and post-earthquake images helped detect visible structural changes, while GIS supported the classification of damage into slight, moderate, severe, and complete collapse categories. The result showed that moderate and severe damage categories were more prominent, indicating the need for urgent inspection, repair, retrofitting, and reconstruction. GIS-based damage maps also helped identify priority zones where rescue teams, medical support, and relief materials were required immediately. Overall, the application of Remote Sensing and GIS improves the speed, accuracy, and efficiency of earthquake damage assessment. These technologies not only support post-disaster response but also help in future risk reduction, urban planning, vulnerability mapping, and resilient infrastructure development. Therefore, Remote Sensing and GIS should be considered essential tools for modern earthquake disaster management and structural safety assessment.

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