

The Regulation of Building Structures in Earthquake Disasters by the Internet of Things

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Abstract. The earthquake occurred suddenly and was extremely destructive, with buildings collapsing and structures being damaged being the core causes of casualties and economic losses in the disaster. Traditional building earthquake protection is difficult to meet the current urgent needs for disaster prevention in urban high-rise buildings. By relying on the IoT to build a sensor network, cloud data analysis and terminal linkage execution system, a full-process active prevention and control is achieved, including long-term pre-earthquake monitoring and warning, real-time dynamic protection at the epicenter, and rapid post-earthquake loss assessment and evaluation. This article details the practical principles, application advantages and domestic and international implementation projects of the IoT participating in building earthquake regulation; at the same time, it objectively points out the existing loopholes and practical obstacles in the current technology implementation; finally, based on personal research insights, it makes an outlook on the future development of the industry, providing practical references for building smart disaster prevention buildings in earthquake-prone areas.

Keywords: Internet of Things; building earthquake protection; intelligent disaster prevention; pre-earthquake monitoring; loss assessment.

1. Introduction

Shallow earthquakes caused by plate movement can easily directly damage the main structures of urban and rural civilian residences and public buildings, and can also lead to secondary disasters such as fires, gas leaks, and wall collapses, further magnifying the losses from the disaster [1]. For a long time, countries with high earthquake activity around the world, such as Japan, Turkey, and China, have mainly enhanced the seismic resistance of buildings by strengthening the hardness of the building structure, installing isolation accessories, and adding energy dissipation devices [2]. However, this traditional protection approach only stays at the static reinforcement level, unable to capture the changes in seismic waves in real time, nor can it flexibly adjust the protection intensity. Post-disaster hazard investigation is entirely dependent on manual on-site work, which is not only inefficient but also poses a significant safety risk to the staff themselves [3].

In recent years, the Internet of Things (IoT), micro-sensing devices, edge computing, and intelligent algorithms have been continuously upgraded, and building earthquake resistance has finally shifted from the simple "passive hard resistance" to a brand-new direction of "active intelligent protection" [4]. Overseas scholars have long been deeply engaged in the research of IoT in the fields of building structure monitoring, earthquake early warning, and intelligent vibration reduction, and have also implemented multiple practical models; domestically, smart earthquake resistance renovation pilots have gradually been carried out in key buildings such as hospitals, office buildings, and schools [5].

2. Traditional methods for regulating housing construction under earthquake disasters, their drawbacks, and the advantages of integrating the IoT

2.1. Traditional regulatory mainstream methods

Deep reinforcement of walls. By thickening beams and columns, increasing the density of steel bars, installing structural columns and seismic shear walls, the overall stability of the building is

strengthened, and the structure's strength alone is relied upon to withstand the impact of earthquakes. During the post-earthquake reconstruction phase in Wenchuan, a large number of self-built rural houses and old brick-concrete buildings in urban areas across the country uniformly adopted the reinforcement method of combining ring beams with structural columns, enhancing the seismic resistance baseline from the fundamental level [6]; in Europe and America, low-rise brick and stone residential buildings also commonly use steel mesh plastering to reinforce walls, reducing the risk of cracking and collapse [7].

Passive isolation and measure-based vibration reduction. In the building foundation or floor slabs, rubber isolation pads, viscous dampers, and frictional energy dissipation components are installed to block the transmission of seismic waves and consume the vibration energy. The natural rubber isolation system developed by the Lin Y.S team from Japan has been widely used in the terminal building of Tokyo Haneda Airport and several super-tall office buildings in Osaka [8]; in Taiwan's 101 Building and several landmark buildings in Guangzhou, hydraulic shock absorption components are also equipped, which can significantly reduce the building's shaking amplitude during strong earthquakes [9].

Manual inspection and post-disaster on-site assessment. Daily inspections are conducted by professional personnel who visit the site regularly to record potential hazards such as wall cracks, rusted steel bars, and subsidence of the foundation. After an earthquake, expert teams conduct on-site inspections of each building, classify dangerous houses, and delineate danger zones. In the aftermath of the 1976 Tangshan earthquake and the 2023 strong earthquake in Turkey, both countries relied on full-scale manual surveys to determine the safety of buildings, thereby supporting post-disaster resettlement and reconstruction planning [10].

2.2. The core drawbacks of the traditional regulatory model

The emergency response was severely delayed. Traditional buildings lacked real-time earthquake sensing and warning devices. Before an earthquake occurred, they were unable to automatically cut off power, gas supply, or stop elevators. Secondary disasters such as gas explosions and electrical fires occurred frequently [11]. Research conducted by Abdulzaher M.S. et al. in 2023 indicated that in buildings relying solely on passive earthquake resistance measures, the losses caused by secondary disasters during strong earthquakes could account for more than 40% of the total losses [12].

The monitoring coverage is narrow and the data is rough. Routine inspections are conducted at fixed points and at regular intervals, which makes it impossible to continuously capture the subtle deformations and stress changes of the building [13]. Early hidden damages are difficult to be detected, and over time, major safety hazards are highly likely to be triggered. Olivito R.S. mentioned in his 2021 research that there are obvious problems such as multiple blind spots in manual inspections, inconsistent data, and large errors in personal judgment [14].

The protective tools are fixed and uniform. The isolating pads and dampers are preset parameters at the factory and cannot be flexibly adjusted to achieve different levels of shock absorption based on the frequency and magnitude of the seismic waves. In the event of a strong earthquake that exceeds the preset seismic resistance level, they are likely to fail directly [15].

The renovation cost is high, and the applicable scope is very limited. Traditional reinforcement projects have long construction periods and high costs. Ancient buildings and old, simple houses simply cannot be extensively renovated, and advanced seismic protection technologies are difficult to be widely adopted [16].

2.3. The core value of integrating the IoT with traditional regulation

Introducing IoT technology can precisely fill all the shortcomings of traditional protection:

Achieve all-round and round-the-clock perception, with lightweight sensors fully deployed, capturing real-time data on building vibrations, displacements, and tilts, and accurately identifying subtle structural changes [17];

Achieve second-level early warning, relying on rapid seismic wave recognition algorithms, issuing warnings tens of seconds in advance, leaving crucial time for personnel evacuation and equipment emergency shutdown [18];

Achieve flexible protective measures, linking intelligent dampers and adjustable isolation components, adjusting protective parameters in real time to adapt to different intensities of earthquakes [19];

Achieve rapid post-disaster loss assessment, automatically comparing structural data in the background, quickly generating safety assessment reports, replacing high-risk manual inspections [20].

3. The IoT and the regulation mechanism, advantages and examples of housing buildings in earthquake disasters

3.1. The overall technical architecture of the IoT regulation

The complete IoT seismic protection system is divided into four layers: the perception layer, the transmission layer, the platform layer, and the execution layer.

The perception layer involves installing acceleration, stress, and tilt sensors on the building itself to continuously collect seismic waves and dynamic data of the building structure [17]; Martinez F, in the 2025 Chile Concrete Building Monitoring Project, used high-precision sensing equipment to achieve millisecond-level collection of vibration and deformation data [19].

The transmission layer relies on 5G and low-power wide-area communication technologies to ensure stable data transmission during extreme disasters without interruption [18].

The platform layer combines big data and intelligent algorithms to determine the risk level and automatically generate protection instructions [12].

The execution layer controls shock-absorbing equipment, emergency valves, fire protection and elevator systems to complete the fully automated safety control [20].

3.2. The core path and advantages of intelligent control in the Internet of things

Conduct regular health protection before an earthquake occurs. Continuously monitor whether the buildings are aging, whether the foundations are sinking, and whether the components are deteriorating. Establish a complete safety record covering the entire cycle, precisely push out maintenance plans, reduce the probability of earthquake damage at the source [13], and significantly lower the cost of manual monitoring.

Real-time active protection during an earthquake. Once the earthquake warning is triggered, the system immediately adjusts the parameters of the shock-absorbing equipment, locks the isolation structure, and reduces the shaking of the building; at the same time, it automatically cuts off gas and electricity, and shuts down the elevators, effectively preventing secondary disasters [15]. Roghaei M's civil building protection system in Tehran, which was established in 2024, can complete the emergency water and power cut-off for all buildings in the city within ten seconds, effectively curbing the spread of fires [17].

After the earthquake, quickly locate and plan rescue and reconstruction plans. Relying on the data from the background system for comparison, accurately determine the damaged areas of buildings and classify dangerous houses, providing precise basis for the rescue teams to plan routes and formulate reconstruction plans [20].

Compared with the traditional mode, the IoT earthquake resistance early warning is timelier, the protection is more precise, the layout is more flexible, and the later operation and maintenance is more cost-effective. It is particularly suitable for the renovation and implementation of old buildings and public buildings such as schools and hospitals [18]. In practical application, the IoT earthquake resistance not only can effectively control earthquakes but also can minimize the occurrence of

secondary accidents to the greatest extent, and at the same time significantly reduces the cost of personnel monitoring and measurement in the early stage.

3.3. Domestic and international application examples in the field

The coastal building monitoring project in Valparaíso, Chile, was established by the Martinez F team, which set up an IoT sensor network to continuously track the seismic resistance performance of concrete buildings. During strong earthquakes, it could optimize the shock absorption parameters in real time, reducing the proportion of building damage by more than 30% [19].

The smart city cluster in Kansai, Japan, integrates the IoT with earthquake early warning systems, allowing residents to have 15 to 30 seconds of evacuation time, significantly reducing casualties [8].

The residential protection project in the urban area of Tehran, Iran, combines fuzzy logic and the IoT to achieve automatic shutdown of public facilities after an earthquake, effectively avoiding risks of fire and gas explosion [17].

The Chong'an County Central Hospital in Sichuan Province has established a multi-dimensional IoT earthquake-resistant system, accurately responding to numerous small-scale earthquakes multiple times, and the emergency equipment in the hospital is fully automatically linked throughout the process.

4. The defects and shortcomings of the IoT in regulating residential buildings during earthquake disasters

4.1. Inherent technical weaknesses

Under extreme disaster conditions, the stability of equipment will be affected. Intense shaking caused by strong earthquakes, dust blocking, and electromagnetic interference can easily lead to sensor data deviations and malfunctions; after communication base stations collapse, the transmission layer functions are lost, resulting in data transmission interruptions, command delays, and direct failure of core protection functions [14]. The experimental data from Won J et al. in 2020 shows that for ordinary civilian low-cost sensors, the data error rate can reach more than half in earthquakes of magnitude 7 or above [20].

Monitoring capabilities and algorithms have limitations. Most existing models are trained using conventional seismic data. When dealing with extremely long-period earthquakes, mountainous complex terrains, and irregular ancient buildings, their accuracy in judgment is insufficient, making it difficult to predict the critical point of building collapse in advance [12].

Industry technical standards are not unified. The sensing devices and control systems from different manufacturers cannot be compatible, and the data are isolated from each other. It is extremely difficult to achieve cross-building and cross-region interlocking protection [18].

4.2. Challenges in on-premises application deployment and operation and maintenance

The initial installation cost is relatively high. Large-scale deployment of sensors, construction of the back-end platform, and professional debugging and maintenance result in high expenses. It is difficult for small and medium-sized cities, county towns, and rural areas to achieve comprehensive promotion, and they can only pilot and apply it in a few key buildings [16].

There is a shortage of professional talents. This field requires specialized individuals who possess knowledge in both earthquake engineering, IoT technology, and intelligent algorithms. Currently, there is a significant gap in the industry, and many pilot projects have no one to maintain them later on. The systems gradually become idle and cannot operate stably in the long term [13]. Cybersecurity vulnerabilities. If the IoT system is maliciously invaded or data is tampered with, it may trigger incorrect protection instructions, thereby creating significant security risks [11].

4.3. The absence of systems and supporting frameworks

Currently, there are no unified standards for the design, construction and acceptance of IoT earthquake-resistant buildings worldwide; in China, this intelligent protection technology has not been incorporated into the mandatory seismic resistance standards for buildings, and the related support policies and subsidy mechanisms are not complete, resulting in a serious lack of market promotion momentum [16]. At the same time, the building earthquake-resistant IoT system and the urban emergency rescue platform do not have data communication or smooth connection, and after an earthquake occurs, the efficiency of resource allocation and coordinated rescue is greatly reduced [20].

5. Conclusion

In the face of disasters, I always believe that advanced technology is the most solid guarantee for safeguarding life safety. The traditional passive reinforcement earthquake-resistant model has long failed to keep up with the complex urban architectural layout and cannot withstand the violent impact of sudden strong earthquakes. However, IoT technology has given cold buildings the "nerves" to sense risks and the "brain" for autonomous protection, breaking the old thinking of post-disaster remediation and truly achieving a full-chain protection of pre-event monitoring, in-event control, and post-event rescue. It secures basic safety through real-time monitoring; resists earthquake impacts through intelligent linkage and opens rescue channels through rapid loss assessment. Every pilot application can vividly demonstrate the huge disaster reduction value.

However, we must also clearly recognize the reality: At present, the earthquake-resistant protection of the IoT still faces many problems such as immature equipment, poor durability, algorithm flaws, unaffordable costs, and inconsistent standards. To achieve comprehensive popularization and benefit all residential areas, there is still a long way to go.

Looking to the future, I am full of anticipation for this industry to continuously make breakthroughs: Firstly, it is necessary to deeply integrate digital twins and large-scale artificial intelligence models to build virtual simulation models for buildings, accurately predict the impact of earthquakes, and achieve the most flexible and autonomous protection; Secondly, it is necessary to develop domestic sensing devices that have their own power supply, can withstand strong earthquakes, and are low-cost, to lower the renovation threshold and enable old residential areas and rural houses to also enjoy the guarantee of smart earthquake resistance; Thirdly, it is necessary to unify the technical standards of the entire industry, break through data barriers, and enable deep interaction between building protection systems and urban emergency rescue platforms; Finally, it is necessary to improve relevant policies and regulations, increase the intensity of talent cultivation, and incorporate intelligent IoT earthquake resistance into the mandatory building standards.

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