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Smart Communities to Reduce Earthquake Damage: A Case Study in Xinheyuan, China

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Abstract

Earthquakes frequently cause serious casualties and property loss in China. Building smart communities is an effective means of preventing damage and reducing disastrous outcomes from earthquakes. This article reports on the Chinese experience of building a smart community and the concept of smart service for preventing damage and mitigating disasters from earthquakes in Hubei province. The case study examined the Xinheyuan Smart Community, which is the first such community constructed in Hubei province, including its background development, system design and system functions. The disaster mitigation function was tested when a magnitude 4.9 earthquake occurred in Yingcheng earthquake.

Keywords: earthquake prevention, disaster reduction, smart community, earthquake early warning, Xinheyuan

1 Introduction

Earthquakes are the primary natural hazard in China and the casualties and property losses caused by earthquakes are severe [1–3]. As China's level of urbanisation increases, the number of people living in cities will grow. In many urban areas, communities face unresolved seismic safety issues. Improving the seismic resistance of buildings is the most effective way to solve these safety concerns. However, for economic reasons, this will take many years to be widely implemented because the costs of improving the earthquake resistance of all buildings are prohibitive. Other methods such as early warning systems, which are an effective means of preventing and reducing earthquake damage, can be used as important supplementary measures, and have been widely used

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all over the world [4–8]. The construction of smart cities is gradually being carried out in large and small cities in China, but most focus on aspects such as security, fire-fighting and community service [9–13]. The existing system is basically consisting of front-end sensor, data acquisition, data analysis and data application platform. There are very few reports on communities that feature systems to prevent and mitigate earthquake damage, as well as including other functions such as environmental monitoring.

2 Research status at home and abroad

Disaster prevention and mitigation within communities in China and elsewhere has long been a research focus. For example, Japan has improved the ability of its communities to prevent and mitigate earthquake damage through new network technologies, real-time disaster monitoring and early warning technology, earthquake isolation techniques, emergency drills and emergency medical rescue drills. Japan is a world-leader in the development of disaster prevention and mitigation systems within its communities [14, 15]. Indonesia also uses IT and GIS technology to manage urban disasters and it is building smart cities [15]. Australia has defined disaster-tolerant communities in its national disaster prevention strategy, which clearly state the characteristics of disaster prevention and mitigation in these communities. These characteristics include: awareness among community residents of the risks that may affect them, housing that has better resistance to natural disasters and a good organisational structure within the community [16]. Duft (2012) proposed the use of social media for community disaster prevention and mitigation [17]. Guan et al. (2008) studied the mechanisms of disaster prevention and mitigation in urban communities in China, and proposed basic institutions to improve resilience [18]. Zhang (2012) identified that adequate resource allocation and management optimisation were the most important elements for successful disaster prevention and reduction in communities [19]. In China, the National Disaster Reduction Center has formulated the approaches that are required for community disaster prevention, including day-to-day protection and actions during and after the occurrence of earthquakes. General Secretary Xi Jinping has clearly indicated that disaster prevention, mitigation and relief is an important manifestation of the leadership ability of the ruling party.

The construction of smart communities can play a vital role in disaster reduction. Smart phones are an effective way to use big data to enhance a smart community's crisis response and disaster resistance capacity [20]. The 'Smart Service', one of four major projects in the Science and Technology Innovation Projects of the China Earthquake Administration, is a 'cloud + terminal' smart service system for providing damage prevention and reduction information in the event of an earthquake [21]. The construction of a smart community to improve seismic safety is a useful exploration of the 'Smart Service' concept. China's Earthquake Intensity Quick Report and Earthquake Early Warning Project will be officially put into operation in 2022, by which time the entire system for earthquake early warning information will have been rolled out to major projects and people across the country. The introduction of smart earthquake warning services in urban communities is imminent.

It is evident that the construction of communities that are resilient to earthquake damage has long been an important research focus. However, there is little research on how to use modern scientific and technological methods and mature technologies to create smart communities to reduce the damage caused by earthquakes. This paper used the first earthquake disaster mitigation smart community in Hubei province—the Xinyuan Earthquake Prevention and Disaster Mitigation Smart Community (Xinyuan Smart Community) in Wuhan—as a case study. The design and functional implementation of earthquake disaster reduction measures were explored. These will provide a reference for the construction of other smart communities in the future.

3 Demand analysis for the Xinyuan Smart Community

The Xinyuan district is located in Jinghe Street, Dongxihu District, Wuhan, and was completed in 2016. Reducing damage from earthquakes is at the forefront of work in the Earthquake Office of the Dongxihu District

in Hubei province. In 2018, the Earthquake Office of Dongxihu District selected Xinheyuan as a demonstration site to build the first smart community in Hubei Province featuring earthquake damage prevention and disaster reduction systems. The project aimed to allow residents in the community to use smart technology to obtain information on earthquake preparedness and enhance disaster resilience. The preliminary work of this project focused on identifying the desired functions and performance requirements through surveys and communication with the construction company and community residents. The results are shown below.

1. Functional requirements

- (a) Earthquake early warning. Surveys showed that most community residents wanted to know in advance when the earthquake would occur and how much impact it would have on their home. Since it is not possible to accurately predict earthquakes at this time, we recommended that the residents could receive messages from an earthquake warning service.
- (b) Structural safety assessment. When buildings were under construction, homeowners were concerned about the impact on the building if there was an earthquake, including whether it needed to be strengthened and whether they would be able to continue to live there safely. In this case, we recommended selecting a typical high-rise building to deploy a structural array which could provide a real-time online risk assessment of structural safety after an earthquake. If the assessment showed a high risk, an alarm message would be generated and pushed to the residents.
- (c) Earthquake emergency drills. The Dongxihu District Earthquake Administration found that practice drills were an effective means of enhancing residents' preparedness for earthquakes. The Dongxihu District government hopes that the construction of the Xinheyuan Smart Community will enable better earthquake emergency drills, based on the existing system. An installed earthquake warning terminal in the community will be able to simulate an earthquake, and community managers and residents will be able to organise personnel and conduct escape drills through an app after prior notice.
- (d) Environmental information. Residents also wanted to know the environmental information in the community, including PM2.5, PM10, rainfall and temperature. For example, if there were high pollution levels of PM2.5, residents could be reminded to take protective measures.

2. Performance requirements

- (a) Accurate and in real time. The system needs to ensure that the published information is correct, especially the earthquake warning information. If an error occurs, this will lead to other social problems. It is also important to ensure the timeliness of the published information, to fulfil the roles of providing a warning and enabling disaster reduction.
- (b) Understandable. Since the users of the system are community residents, the design of the system needs to be easy to understand. This can be done by using familiar terminologies and appropriate warning reminders to ensure that the content pushed by the system is acceptable for the majority of residents.
- (c) Secure. The system needs to ensure the security of data, prevent hacking and set user permissions to guarantee the integrity of the system.
- (d) Useful. Widespread acceptance by community residents will depend on whether the service is useful. The initial objective of the system design is to satisfy the user, and this indicator must be considered.

4 Development of the Xinheyuan Smart Community system

4.1 System design

Since there are no relevant standards and regulations yet that could be followed in the construction of a smart community for preventing and reducing damage from earthquakes, the system made full use of existing smart services. The main aspects were as follows: (1) using the Internet of Things, big data, cloud platforms and other advanced technology; (2) using the nearly completed national Earthquake Intensity Quick Report and Earthquake Early Warning Project to serve community residents; (3) establishing a structural seismic monitoring array to facilitate a rapid building safety assessment after an earthquake; and (4) real-time monitoring of the community environment and timely dissemination of alarm information. The overall framework of the Xinheyuan Smart Community is shown in Figure 1.

From Figure 1, we can see that the information input to the Xinheyuan Smart Community mainly includes three aspects: national Earthquake Intensity Quick Report and Earthquake Early Warning information, structural vibration information monitored by structural arrays and community environment information monitored by environmental monitors. The information output of the Xinheyuan Smart Community is mainly focused on early alert and alarm information. These information sources can be used directly for disaster prevention and reduction.

Fig. 1 The overall architecture of the Xinheyuan Smart Community system.

Figure 2 shows the overall architecture of the Xinheyuan Smart Community system. It can be seen that the system is mainly composed of four subsystems: front-end monitoring, data transmission, data processing centre and alert and alarm information release.

Fig. 2 Overall architecture of the Xinheyuan Smart Community system.

The front-end monitoring subsystem includes a number of sensors and data collectors, as follows: strong vibration monitoring sensors, wind speed and direction monitoring sensors, rainfall monitoring sensors, PM2.5 sensors, PM10 sensors, noise sensors and supporting data collectors.

The data transmission subsystem uses a wired mode and transmits the monitored data to the Alibaba Cloud server in real time through the wired network RJ45 interface.

The data processing centre includes an application server, data analysis and management subsystem and an alert and alarm push subsystem. The Alibaba Cloud server enables real-time data collection and forwarding to the application server. The data analysis and management subsystem, early alert and alarm information release subsystem are deployed on the application server. The data analysis and management subsystem enables the classified management of the monitoring data and the safety assessment of the building structure after an earthquake. The early alert and warning information release subsystem has access to national earthquake warning information, environmental warning information and structural safety assessment warning information, and pushes the information out in accordance with the preconfigured logic.

The early alert and alarm information release subsystem uses PC terminals, a mobile phone app, alarms, community broadcast and specialised terminals to release the information externally.

Figure 3 shows the installation site map of the Xinheyuan Smart Community, including the construction of instrument piers for the structural monitoring arrays, the installation of strong seismic instruments, the installation of environmental monitors and the construction of the data centre.

The total cost of the smart community is ¥390,000, and it is acceptable in China.

(a) Pouring construction of instrument pier with strong seismograph

(b) Strong Seismograph Equipment Installation

(c) Environmental Monitor Installation

(d) Data Center of Smart Community for Earthquake Prevention and Disaster Reduction

Fig. 3 Installation site map of the Xinheyuan Smart Community.

4.2 System function

The main function of the Xinheyuan Smart Community is preventing and reducing earthquake damage. The main interface of the software is shown in Figure 4. The specific functions include the following:

(a) Earthquake early warning service

The system uses the national seismic Earthquake Intensity Quick Report and Earthquake Early Warning Project to deliver an early warning information push service for the area surrounding an earthquake, solving the problem of a lack of earthquake early warning for nearby residents.

(b) Post-earthquake building safety assessment and earthquake warning

After an earthquake, the response of buildings can be evaluated by the acceleration time-history curves generated by strong earthquake monitors that are installed on different floors of the structure. The monitors will

give a post-earthquake safety evaluation report for the building and send an earthquake warning message.

(c) Environmental quality alarm

Real-time monitoring of the environment in the community is achieved through environmental monitors placed in the entrances and exits of the community and outdoor fitness centres. Warnings of ultra-high values of PM2.5, PM10, temperature, humidity and wind speed will be pushed to the residents of the community, so that they can modify their travel plans and methods.

(d) Earthquake emergency drills

Since preparedness ensures success, and unpreparedness usually results in failure, this system is designed to simulate an earthquake, which enables community residents to practice earthquake emergency drills, including self-protection measures during the earthquake and staying calm to deal with the post-earthquake situation.

Fig. 4 Main interface of Xinheyuan Smart Community software.

5 Verification of the seismic response of the system

An earthquake of magnitude 4.9 occurred in Yingcheng, Hubei, on 26 December 2019. The epicentre was 76.11 km away from the Xinheyuan Smart Community, as shown in Table 1. The system recorded the impact of the earthquake on the high-rise building. Figure 5 shows the acceleration time-history curve of structural unit of Xinheyuan during the earthquake. The system performed a risk assessment to determine the structural safety of the building, and showed the structure safety assessment report via the platform. The PGA of ground floor is 1.526 gal, and that of the top floor is 4.264 gal. The ratio of PGA (top/ground) is approximately equal to 3. We can see amplification effect as the height of the building.

This case of emergency response during the 4.9-magnitude earthquake of Yingcheng, Hubei shows that the smart community emergency response system researched in this paper has important theoretical significance and practical value.

Table 1 Basic information on the earthquake in Yingcheng on 26 December 2019.

Magnitude (surface wave magnitude)	Onset time	Epicentral latitude	Epicenter longitude	Focal depth	Shock location	Epicentral distance
4.9	18:36, 26 December 2019	30.87 degrees	113.40 degrees	10 km	Yingcheng, Hubei	76.11 km

Fig. 5 Acceleration time-history curve of the Xinheyuan Court building during the 4.9-magnitude earthquake in Yingcheng, Hubei.

6 Summary and outlook

China is an earthquake-prone country, and community safety during and after earthquakes needs to be a high priority. The prevention and mitigation of earthquake damage through smart communities can improve the lifestyle quality of the community. Smart communities are an effective means to implement disaster prevention and mitigation. With the development of the Internet of Things, cloud computing, artificial intelligence and advanced technology, the smart community will soon become part of people's daily lives.

This paper used the Xinheyuan Smart Community as a case study to describe the system design, functions and construction process. This is the first smart community system for preventing and reducing earthquake damage in Hubei province. The system played an important role in disseminating information regarding the magnitude 4.9 earthquake in Yingcheng, Hubei province on 26 December 2019. The response of the community provides a reference for the system construction standards and engineering for other smart communities for preventing and reducing earthquake damage.

The number of smart communities able to mitigate and reduce damage from earthquakes will increase as people's living standards improve, but the correct development process must be encouraged. And the front-end sensor needs to be various to satisfy multiple needs. The project needs to be continuously improved and updated based on new technologies and new community needs. Smart communities for earthquake and disaster management should also be combined with security and health information to establish a unified management platform to integrate data and better serve urban residents.

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