Development of quasi real-time comprehensive evaluation system for earthquake disaster

Zhi Liu¹,²,³, Hui Jiang¹,²,³ and Lanfang Zhang⁴

¹Shenzhen Academy of Disaster Prevention and Reduction, Shenzhen, China;
²Guangdong Earthquake Agency, Guangzhou, China;
³China Earthquake Administration Shenzhen Training Center, Guangzhou, China;
⁴South China University of Technology, Guangzhou, China

Email: liuzhi8725@126.com

Abstract. Fast acquisition of the seismic information and accurate assessment of the earthquake disaster is the key problem for emergency rescue after a destructive earthquake. In order to satisfy the requirements of the earthquake emergency response and rescue for the cities and counties, a quasi real-time comprehensive evaluation system for earthquake disaster is developed. This software system has the functions of gathering disaster information, analyzing seismic damage and estimating disaster extent. To prop up such a powerful software platform, data and algorithms are prerequisites. As a result, Micro-Electro-Mechanical System (MEMS) is developed to monitor strong motion underground, application programs for data collection by the mobile terminal are also developed to acquire the basic structural data and disaster information. Besides, based on short-distance emergency communication technology, a set of short-distance multi-modes are designed to transmit those critical data to the evaluation system. After a certain earthquake, using fragility analysis method and dynamic correction algorithm, together with the basic data, seismic disaster evaluation in the county region is finally realized in real-time to provide a scientific basis for seismic emergency command, rescue and assistant decision.

1. Introduction

China is an earthquake-prone country and 50% of its area is located in seismic zone with high intensity of VII, covering 23 provincial cities and 2/3 other principal cities with an urban population of more than one million. Since the middle of last century, 445 earthquakes of Ms 6.0-Ms7.9 and 9 earthquakes of Ms 8.0-Ms 9.0 attacked China, result in more than 590,000 of death [1]. For instance, Tangshan earthquake, Wenchuan earthquake and Yushu earthquake have brought us serious disaster and caused immeasurable loss and influence to the society and economy.

After a catastrophic earthquake, acquirement of the comprehensive disaster information and estimate the earthquake loss as fast as we can to provide firsthand information to the government and relevant departments becomes the key problem, which also influences emergency rescue deployment after the earthquake. The local organization of earthquake prevention and disaster reduction work, seismological departments of the county are in urgent need of confirming disaster condition and influence area to develop a scientific seismic emergency rescue plan. However, vast landscape of the county and inhomogeneous distribution of the residents make it difficult to acquire seismic basic data. Meanwhile, lack of scientific and technical support for the local seismological departments causes the government hard to integrate the multisource seismic information and evaluate the disaster promptly.
So far, seismic disaster data are mainly acquired by means of quick evaluation, artificial investigation and remote sense image after an earthquake in China. Traditional method using seismogram to evaluate seismic disaster is widely used in some developed countries [2]-[6]. For instance, American Elarms system and Japanese Signore system are both utilizing the data from earthquake monitoring networks by sufficient density of accelerometers or velocity seismographs to obtain the seismic intensity map and release the information of intensity distribution to the public[7]. However, with a vast territory and insufficient seismographic stations, as well as amplitude limit of the seismographs in some violent earthquakes, the seismic map is too rough for decision-making. Besides, owing to the randomness and uncertainty of the quick evaluation results, disaster condition should be further confirmed by artificial investigations and remote sense images [8], [9]. Even though the artificial investigation methods and means are improving, wide distribution of damaged buildings and casualties, deteriorated weather and road condition make it hard and time consuming to investigate the seismic disaster information. As a new and highly efficient technique, remote sensing has the advantages of prompt acquisition, large quantity, short cycle and dynamic monitoring for disaster information. However, some outstanding problems still exist including easily obstructed by the weather and difficult to process mass images [10], [11]. In addition to theoretical methods, novel data sources have been leveraged to improve emergency awareness and disaster management such as remote sensing (RS), mobile phone (MP), and social media (SM), with remarkable advantages of low acquisition cost, real-time updates and high spatio-temporal resolutions [12]. Overall, quick evaluation methods and techniques by far cannot meet the requirement of seismic emergency response. In order to solve these problems, using data integration technology and superposition method from the latest technical achievements, a comprehensive evaluation system of quasi real-time earthquake disaster is developed which integrate multisource data of MEMS strong motion, real-time earthquake disaster data and other seismic information. Through the superposition analysis of mathematical models, assessment value of quasi real-time dynamic disaster can be obtained. With the characteristics of automatic triggering, real-time update and comprehensive assessment, this system can efficiently and quickly integrate the basic data of earthquake information and estimate seismic disaster. At the same time, based on the short distance communication module, even when the public communication is knocked out, seismic information can also be transmitted and real-time update. Danleng county in Sichuan province of China has been chosen to carry out integrated demonstration, once the county is shocked by a harmful earthquake, seismological departments of the county can quickly obtain the earthquake disaster distribution accurately by the evaluation system, and provide scientific decision and strive for precious time for earthquake emergency rescue.

2. System function
The quasi real-time evaluation system of earthquake disaster is an integrated service platform dedicated to solving the earthquake emergency work for seismological departments of the city and county (Figure 1). In order to meet the requirements of rapid and accurate assessment of the earthquake disaster, four core modules are developed in this system corresponding to different time nodes during an earthquake.

(1) Generating earthquake influence field. Peak acceleration curve and seismic intensity scatter diagram are acquired in this module to provide first-hand earthquake information and essential parameters for seismic disaster assessment.

(2) Rapidly evaluating earthquake disaster. Structural damage assessment results in the county by the unit of town are obtained in a very short time after an earthquake to provide preliminary scientific basis for seismic emergency.

(3) Dynamically updating seismic disaster. Structural damages, casualties and road blocking conditions are updated and showed in real time in this module. Meanwhile, based on the collected disaster data, the assessment results of earthquake disaster can be dynamically corrected.

(4) Comprehensively assessing seismic disaster. Based on the three indicators including structural damages, casualties and intensity distribution of the disaster areas, the disaster damage grade can be
synthetically evaluated, and the distribution of earthquake disaster in towns and even though in villages can be obtained more accurately than rapid evaluation results.

3. System models and algorithm introduction

The mathematical models and algorithms are essential for this quasi real-time disaster evaluation system, which are directly related to the efficiency and accuracy of the assessment results. The main models of this system include MEMS disaster assessment model, disaster dynamic correction model and disaster comprehensive assessment model.

3.1. MEMS disaster assessment model

Based on the peak acceleration database of 45 MEMS seismographs, MEMS disaster assessment model is set up by site and terrain correction algorithm, interpolation algorithm, transformation formula for seismic intensity and peak acceleration, vulnerability of buildings, the peak acceleration scatter, instrument intensity scatter, peak acceleration curve and damage evaluation map of buildings are obtained. The specific process is shown in Figure 2.

3.1.1. Site and terrain correction algorithm for seismic peak acceleration. As a demonstration area, the terrain effect is obvious in the north of the Danleng county with mountains which are different from the south with flat terrain. Using linear interpolation algorithm to calculate grid peak acceleration, large error will be created. Meanwhile, considering the influence of different site on seismic peak acceleration, the dual effects of site and terrain must be considered in the calculation of the peak acceleration value of grid points in Danleng County.

Firstly, the original peak acceleration $A_i$ recorded by 45 strong seismographs should be corrected by the site and terrain, and the peak accelerations at the same rock surface $A_i'$ can be obtained.

$$A'_i = \frac{A_i}{f_{assi} \cdot f_{ati}}$$

(1)
By linear interpolation of the $A_i$, the peak acceleration value of the interpolation point at the same rock surface $B_j'$ is obtained, and then the peak acceleration values $B_j$ of the actual grid nodes are calculated.

$$B_j = B_j' \times f_{aj} \times f_{aj}$$ (2)

Where, $f_{asi}$, $f_{asj}$ are respectively the site correction coefficients of the instrument point and the interpolation point.

The correction coefficients of the peak acceleration of the instrument and the peak acceleration of the interpolating point are respectively obtained by the topography effect analysis.

$f_{ati}$, $f_{atj}$ are respectively the terrain correction coefficients of the instrument point and the interpolation point, which can be obtained by the topography effect analysis.

### 3.1.2. Generation algorithm for distribution curve of instrumental intensity

The instrument intensity is the fastest and most intuitive evaluation index to reflect the degree of earthquake disaster, which has a guiding significance for emergency response. The calculation method of instrument intensity in this system is the conversion formula of the US ShakeMap system, and the peak acceleration PGA and the peak speed PGV are both used in the calculation.

$$I_{mm} = 3.66 \log(PGA) - 1.66$$ (3)

When $Imm<5$,

$$I_{mm} = 2.2\log(PGA) + 1.00$$ (4)

When $5<=Imm<=9$,

$$I_{mm} = 3.47\log(PGV) + 2.35$$ (5)

Firstly, using formula (3) and (4) to calculate the value of $Imm$, when the value is greater than 7, then formula (3) is adopted.

### 3.2. Dynamic correction model of seismic disaster

Dynamic correction of seismic disaster is to amend the results of the existing disaster assessment based on the real time collection of disaster information. The correction model is actually the intersection operation between evaluation data and collection data, which means using the initial disaster prediction data set $U_i$ as the base set, the disaster collection data set $D_i$ as the real-time updated disaster data, and the $U_i$ and $D_i$ sets are combined and calculated by intersection algorithm, and the $U_i$ set is corrected to get the new disaster set $Di'$ (Figure 3).
In this section, the initial disaster prediction data set $U_i$ includes the predicted damage numbers and distribution of buildings. The disaster collection data set $D_i$ includes the field investigation results by disaster collector, aerial photography, information uploaded by mobile app for disaster collection and act.

![Figure 3. Disaster dynamic correction model.](image)

### 3.3. Comprehensive evaluation model of seismic disaster

Based on casualty, building damage and intensity impact, the comprehensive evaluation model of seismic disaster has been set up to estimate disaster level and comprehensive index of the county at different time nodes after an earthquake. According to earthquake disaster situation, the classification of disaster area can be divided into four grades, general disaster area, heavy disaster area, serious disaster area and severely damaged area (Table 1).

| Disaster area classification | Casualty   | Building damage/damage index | Seismic intensity of the area | DAI (reference value) |
|-----------------------------|-----------|-----------------------------|------------------------------|-----------------------|
| General disaster area       | None/Few  | Slightly (<0.1)             | 6                            | 0.05                  |
| Heavy disaster area         | Slightly  | Heavy (0.11-0.3)            | 7                            | 0.05-0.2              |
| Serious disaster area       | Serious   | Serious (0.31-0.5)          | 8                            | 0.2-0.4               |
| Severely damaged area       | Disastrous| Disastrous (>0.5)           | ≥9                           | >0.4                  |

The comprehensive disaster index (DAI) can be adopted to assess the degree of disaster in a particular region.

$$D_{AI}(i) = \frac{k_1 \times D_P(i) + k_2 \times D_H(i) + k_3 \times D_I(i)}{k_1 + k_2 + k_3}$$  \hspace{1cm} (6)

Where, $D_P(i)$ is the influence factors of the deaths and disappearances, the range of DAI(i) can be refereed by Table 1. $D_P(i)$ is the influence factors of seismic intensity. $D_H(i)$ is damage index of the buildings. $k_1$, $k_2$, $k_3$ are respectively the weight coefficient of $D_P(i)$, $D_H(i)$ and $D_I(i)$, which are usually taken as 0.4, 0.3 and 0.3 respectively.

### 4. System architecture and integration

#### 4.1. System architecture

The B/S framework is used in the quasi real-time disaster comprehensive assessment system, which is divided into two parts, disaster comprehensive evaluation system and data management system. The
display system is designed and constructed by open source framework using Flex interface, Spring MVC, MyBatis and JavaEE are applied in the development of the system model layer and the persistence layer. Data transferring and disaster analysis algorithm are also realized to provide users efficient and convenient disaster analysis and display service.

4.2. Interface design
According to the overall structure level, the user interface of the quasi real-time comprehensive evaluation system of seismic disaster is composed of 5 functional modules. The functional modules include the MEMS disaster assessment, the dynamic collection of seismic disaster, the dynamic correction of seismic disaster, the comprehensive assessment of seismic disaster and the system introduction. Each module is divided into several sub modules and provides different disaster information maps (Figure 4) according to the emergency demand.

![Figure 4. Quasi real-time comprehensive evaluation system interface.](image)

4.2.1. Assessment module for MEMS disaster. Based on the disaster assessment model, MEMS disaster assessment module can quickly obtain the influence field of ground motion in 10 minutes after the earthquake and assess the basic disaster situation in the demonstration area. The disaster information map produced by this module includes peak acceleration scatter map (Figure 5), instrument intensity scatter map, peak acceleration contour map and building damage evaluation map (Figure 6). The number and proportion of different types of buildings corresponding to different damage levels in villages and towns can be obtained by seismic vulnerability analysis method. The main disaster information of this module includes 45 MEMS accelerometers, peak acceleration, instrument intensity, and the number and proportion of different types of buildings corresponding to different damage levels in villages and towns.
4.2.2. **Dynamic acquisition module for seismic disaster.** The main functions of dynamic acquisition module for seismic disaster are real-time updating and displaying the disaster data. By linking the background disaster database, once collection APP get and transport the disaster data, this system will automatically update the disaster data table, and the front system will automatically refresh the information according to the disaster data table every two minutes, including disaster maps of building damage, road blocking and casualties with a warning signal. The main disaster information generated by the module includes the number and proportion of different types of buildings corresponding to different damage levels, the coordinates of road damage points as well as the number of casualties (Figure 7).
4.2.3. Dynamic superposition module for seismic disaster. Based on the model and algorithm of dynamic disaster, dynamic correction module is developed to modify and update the assessment results of the earthquake. The main products of this module are dynamic superposition map for buildings and road disaster with the information of the damage number of the buildings, damage distribution of the roads.

4.2.4. Comprehensive evaluation module for seismic disaster. The main function of comprehensive assessment module for seismic disaster is assessing the disaster grade of different administrative regions after an earthquake. Comprehensive assessment map and disaster index of the administrative area can be obtained in this module to make clear the detailed earthquake disaster information to the public and government (Figure 8).

Through the backstage database the operating functions of entry, query, edit, export and storage of the motion parameters and the disaster data are realized, combined with the five functional modules, disaster information atlas and form are generated to provide technical support for urban earthquake disaster prevention and emergency disposal.

5. Conclusion
Based on JavaEE framework, by use of open source design language Flex, a comprehensive evaluation system of quasi real-time disaster is developed. By the basic data and fragility curves of local buildings, strong motion data of MEMS seismographs and real-time earthquake disaster investigation data, through vulnerability analysis, dynamic correction, overlay analysis methods, a rapid assessment and dynamic correction of earthquake disasters has been achieved. Uncertainty and poor reliability of the seismic influence field have been obviously improved.

The quasi real-time comprehensive assessment chart disaster for seismic disaster generated by this system has considered the urgency and accuracy of the acquisition of disaster information after an earthquake. The seismic prediction map is obtained by quick analysis of ground motions of MEMS seismographs and the vulnerability of the local buildings, which can gain valuable time for earthquake emergency command and disposal. Then, combined with the actual disaster data collected, the disaster prediction map can be modified dynamically, and the dynamic evaluation results of the disaster can be updated continuously, finally, a more and more accurate distribution map of the earthquake disaster will be generated to provide a scientific basis for earthquake emergency rescue.
Figure 8. Comprehensive evaluation map of seismic disaster.

Acknowledgement
The research is supported by the Scientific Research Fund of Institute of Engineering Mechanics, China Earthquake Administration Grant No. 2017QJGJ01, Earthquake science and Technology Spark Project Grant No. XH19072 and National Natural Science Foundation of China Project U1901602.

References
[1] Chen Z T Li Z Q & Han, Z H 2012 Study of spatial population distribution in earthquake disaster reduction- a case study of 2007 Ning’er earthquake Technology for Earthquake Disaster Prevention 7 273-284
[2] Chen W K, He S L 2010 Study on Rapid evaluation method of earthquake damage based on multi-source data Northwestern seismological Journal 32 76-82
[3] Wang Y S Zhou Z H 2008 A hypothesis testing based method for seismic intensity rapid assessment by strong ground motion parameters Journal of Earthquake Engineering and Engineering Vibration 28 49-54
[4] Chen K Yu Y X & Gao M T 2011 Research on Shake Map for Yushu earthquake in Qinghai based on source process Earthquake research in China 27 56-64
[5] Wang X Q Shao H C 2003 Model for fast assessment of earthquake damage and losses considering uncertainty of epicenters obtained from rapid determination of earthquake location Journal of Earthquake Engineering and Engineering Vibration 23 198-201
[6] Xu S S 2012 Construction of the rapidly-reported network of seismic intensity of Chengdu Municipal and consideration Earthquake research in Sichuan 2 35-38
[7] Allen R M. 2009 Real-time earthquake detection and hazard assessment by ElarmS across California Geophysical Research Letters 36 L00B08
[8] Chen K Yu Y X. 2010 Research on Shake Map system in terms of the site effect Earthquake research in China 26 92-102
[9] Tang Q Wang J J 2010 Design of management system for the earthquake intensity sensor network based on IPv6 Transducer and Microsystem Technologies 29 103-106
[10] Liu J H Yang J F 2004 Acquisition of earthquake damage information based on remote sensing technology history, current situation and trend Journal of natural disasters 13 46-53
[11] Ze R Z M. Chen H Z & He J Y 2006 Research on rapid generation system of Shake Map Process in Geophysics 21 809-813
[12] Gao J Zhang Y C & Zhou T 2019 Computational socioeconomics Physics Reports 817 1-104