Development of

Earthquake Disaster Loss Estimation in China

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SUMMARY:
Loss estimation, e.g. fatalities, financial losses and social impacts resulting from strong earthquakes, are critical to earthquake damage prediction, urban earthquake disaster mitigation planning, emergency management and rescue, post-earthquake loss evaluation, rehabilitation and earthquake insurance. The earliest research on earthquake loss estimation can date back at least to the mid-1960s. During the past decades, through the investigation of earthquake damage and loss assessment of several strong earthquakes, and the earthquake damage prediction projects of dozens of cities and enterprises, some relatively integral loss estimation standards and systems have been basically established in China. This paper summarizes the development of loss estimation and existing problems in the actual implementation in China involving the research content, method, software system based on GIS and standard, etc. Moreover, a number of new development trends of future loss estimation are indicated in China.

Keywords: loss estimation; earthquake disaster; emergency response; post-earthquake loss evaluation.

1. INTRODUCTION

Generally, earthquake damage losses can be classified into direct losses and indirect losses. Direct loss is economic loss of corresponding earthquake damages of casualties and physical damage by seismic ground motion, earthquake geological disasters and seismic secondary disasters. Indirect loss is the consequences of direct loss, including both economic activities loss and social psychology effect. According to domestic earthquake industry practices, earthquake disaster relief fund is incorporated in earthquake damage direct losses.

The work of earthquake damage loss assessment is to predict the possible earthquake damage loss of one region in future according to the regional seismic risk and social environment, providing basis for making earthquake disaster mitigation measures, or to assess earthquake damage loss though existing earthquake sites, the known relevant parameters of earthquakes, providing basis for emergency rescue. According to different timeliness service, earthquake damage loss assessment can be divided into different stages: 1) pre-assessment at pre-earthquake, is the earthquake damage disaster simulation though probability earthquake (intensity Ⅵ-Ⅸ) or scenario earthquake based on earthquake damage prediction results to find weakness of earthquake relief, providing strengthen measures of earthquake disaster mitigation for government, and providing basis for city disaster mitigation plan, 2) emergency assessment at co-earthquake (rapid assessment or pre-assessment), immediately gives out meizoseismal intensity, intensity distribution, numbers of deaths, damage situation of buildings, damage situation of infrastructure, key rescue regions and other assessment results during ‘black-box’ period of disaster situation after earthquake occurred according to earthquake emergency database and mathematical model calculation. For the continuously feedback of seismic site situation and disaster information, the original earthquake disaster assessment results need to be updated and modified dynamically, the theory of co-earthquake emergency assessment is similar with ‘pre-assessment at pre-earthquake’. 3) primary assessment at post-earthquake, preliminarily gives results, which should be updated dynamically, of damage level, number of deaths and injures, key rescue target, key emergency target, seismic geology disasters, secondary disaster, social influence and other assessment in 72 hours after earthquake. 4)summary assessment at post-earthquake (assessment of earthquake site loss), assesses the earthquake damage loss by population data, economic data, seismic geology data, seismotectonic, damage situation of engineering structure and other detail basic data collections though sampling survey in 7 days after earthquake.

This paper summarizes the application status of earthquake damage loss assessment in earthquake disaster mitigation framework. The main content of a series of technical standard of earthquake works on site is briefly introduced. And partial achievements of Wenchuan and Yushu earthquake site disaster loss assessments are presented. Finally, the outstanding problems and development direction of earthquake damage loss assessment in China are put forward.

2. APPLICATION OF EARTHQUAKE HAZARD LOSS ESTIMATION

2.1. Earthquake Damage Prediction

Earthquake damage prediction research work of China started from Tangshan 1976 earthquake. The first region carrying out the multistory masonry building earthquake damage prediction was Anyang, North Henan. Since the late 1970s, provinces of Shanxi, Hebei and Henan were classified as main earthquake monitoring areas for years. Therefore, Professor Yang Yucheng of IEM, *et al*. carried out earthquake damage prediction for buildings of Anyang neighborhoods in 1980, and large-scale study of earthquake damage prediction method had been achieved till 1985. Chinese earthquake damage prediction method started relatively later than abroad, but has formed its own characteristics by gradually shaping and developing. In January, 1985, the Ministry of Urban and Rural Construction and Environmental Protection issued the ‘Provisional Specification of Establishment of Standard for Urban Planning on Earthquake Resistance and Hazardous Prevention’. In early 1990s, the State Seismological Bureau issued the ‘Outline of Earthquake Damage Prediction (Draft)’, which made Chinese earthquake damage prediction research work came into a new stage of development. In 1998, The ‘PRC Law on Earthquake and Calamity’ was officially issued and the purpose and significance of earthquake disaster mitigation were indicated by the law.

During the ‘7th Five-Year’ period, ‘8th Five-Year’ period and ‘9th Five-Year’ period, the work of earthquake damage prediction and earthquake hazard loss assessment were comprehensively carried out, earthquake hazard loss assessment was classified as priority subject of the State Seismological Bureau, and trial edition of China Earthquake Damage Prediction Map was made. During the ‘9th

Five-Year' period, earthquake disaster mitigation demonstration research and application were carried out in multiple city-centric regional cities, such as Zigong, Zhangzhou, Quanzhou, Tianjin, etc., which played an important role in earthquake relief work. In 2003, the team led by Professor Feng Qiming of IEM established the first Code for Earthquake Disaster Evaluation and Its Information Management System (GB/T 19428, 2003). So far, It has been finished that the work of the earthquake damage prediction of more than 30 cities and large industrial and mining enterprises, which have made great progress in research and application of national earthquake damage prediction methodologies.

The damage prediction method of constructions is generally divided into two parts, earthquake damage prediction of single building and building groups (Yin and Yang, 2004). Most of these methods need first sampling single buildings according to specific proportion, then giving results of sample houses by computing method of earthquake damage prediction of single building, and finally obtaining corresponding earthquake damage matrix statistically. For large and medium-sized towns or regions, earthquake damage prediction requires a lot of manpower, materials and is time-consuming. In order to solve the problem, Sun and Hu (2005)proposed simulated earthquake damage prediction method of building groups based on existing earthquake damage matrixes in 2005. Gao, *et al*. (2007) put forward the earthquake damage prediction simulation method of urban building groups based on unit damage index. A method for earthquake damage prediction of building groups based on multiple factors (Zhang and Sun, 2010) was proposed, which calculates earthquake damage matrixes under different influence factors respectively and sets area proportion of constructions as weight coefficients of various influence factors.

2.2. Earthquake Emergency Response

During the '9th Five-Year' period, China had accomplished the preliminary construction of the National Commanding Center for Earthquake Disaster Mitigation and the commanding center of two cities and one province (Beijing, Tianjin, Hebei) for earthquake disaster mitigation, which was one of the demonstration project of earthquake disaster mitigation of capital circle, and finished building a national earthquake emergency prompt response system initially. The technical code for provincial earthquake emergency command center was compiled in 2000. During the '10th Five-Year' period, based on the 'National Digital Earthquake Damage Observation Network Project', existing earthquake damage prediction achievements and emergency response system practical experiences, the earthquake emergency response and decision support technology systems of the National Earthquake Emergency Response Command Center and 31 districts have been constructed. 60 key cities have had their earthquake damage report system. All these have basically formed an earthquake emergency command system which contains a three-level architecture of national, regional and city in mainland China (Shuai, *et al.*, 2009). This system played a positive role in emergency rescue during the Great Wenchuan and Yushu Earthquake, and has become an important foundation of emergency respond and command for The State Department and governments at different levels.

2.3. Earthquake Site Disaster Loss Assessment

The assessment work of earthquake site loss in china began with Datong–Yanggao Ms6.1 earthquake in 1989, and the assessment method was firstly extended from research of earthquake damage prediction. Publishing of a series of specifications such as Guideline of Assessment of Earthquake Damage And Earthquake Loss (1990), Detail Rules and Regulations for Earthquake Evaluation (1990), Stipulation for Earthquake Disaster Losses Estimation (on trial) and its supplementary requirement (1997), etc, has made the original method of reporting data by grassroots units changed into the current method of sample survey on site when estimating earthquake disaster losses. Meanwhile, authoritative organizations like national and regional earthquake disaster loss assessment committee have been set up for acceptance of assessment results of earthquake damage. Such method and procedure have always been carried out for earthquake loss assessment of past tens of earthquakes in a couple of years. In 2005, Professor Yuan Yifan took the lead of establishment of the national standards GB/T18204.4 (2005). In 2010, led by Professor Sun Baitao, revise of the original standard was accomplished. The new national standard GB/T18204.4 (2011) presented the assessment method of earthquake damage loss considering decoration damage, and constructed the mechanism and report of disaster situation reporting (Sun and Chen, 2008; Sun and Chen, 2009), which have made assessment of earthquake site disaster loss of China became much more completed and detailed. Besides, the construction of disaster loss assessment software has experienced several stages from those based on DOS environment in the 1980s to those based on Windows environment and database management in the late 1990s (Li *et al.*, 2003; Wang and Ding, 2001), etc.

2.4. Post-Earthquake Rehabilitation

According to relevant regulations of the national standard GB/T 27933 (2011), making full use of direct economic loss assessment results of earthquake site disaster damage, estimation of post-earthquake rehabilitation of disaster area buildings (urban and rural houses, education, health, etc), infrastructures (traffic, electricity, communication, hydraulic engineering and municipal public facilities) and enterprises can be promptly obtained, providing reference for the overall arrangement of post-earthquake rehabilition. Besides, scientific aided decision-making system of earthquake rehabilitation based on GIS was constructed based on the achievements above (Wang, 2010).

3. STANDARDS OF EARTHQUAKE SITE WORK

3.1. Management System for Emergency Command in Earthquake Occurrence Site (GB/T 24889, 2010)

This standard is established in order to adapt to the commands of informatization and standardization construction of earthquake site emergency command technology. It’s developed based on experiences of construction of China earthquake emergency command technology system and took the management mode and methods of earthquake sit emergency command as references. The standard gives out the classification, function requirements, subsystem function division, system architecture and running environment requirements, system data and database requirements of management information system for earthquake site emergency command.

3.2. Technical Requirements of Data Share for Emergency Command in Earthquake Occurrence Site (GB/T 24888, 2010)

In order to adapt to the needs of standardization construction of earthquake site information sharing technology, this standard was developed according to experiences of all previous earthquake site emergency command work and took relevant technologies and methods of information sharing as references. This standard gives out data classification of earthquake emergency command, specific contents and forms of all kinds of data, data format and relevant data coding, metadata and data dictionary regulations, method of data exchange and quality control requirements, and data sharing service requirements, etc.

3.3. Post-earthquake field works-Part 3: Code for field survey (GB/T 18204.3, 2011)

Combined with the earthquake damage experiences of Wenchuan earthquake and other large earthquakes in recent years, earthquake site survey standards of engineering structures and lifeline engineering, survey standard of seismic intensity and sensible range, site survey standard of causative structure and standard of seismogeological disaster are given out respectively. The newly revised survey standards especially emphasize seismic damage investigation of primary and junior schools, hospitals and other buildings and the collection of strong earthquakes or aftershocks observation records, etc.

3.4. Classification of Earthquake Damage to Buildings and Special Structures (GB/T 24335, 2009)

The earliest usage of damage levels in assessment of seismic damage of engineering structure can be traced back to Urumqi earthquake in 1964, by the time of Haicheng 1975 earthquake and Tangshan 1976 earthquake, basic foundation of damage level division standard had been confirmed. Thereafter various types of damage level division standard have formed gradually.

According to following principles: ‘mainly considering damage degree of bearing members and taking damage degree of non-bearing members into account, and taking the difficult degree of repair and function loss degree into consideration’, using form of ‘damage quantity and degree’ divide seismic damage levels of buildings or special structures, seismic damage degree of buildings or special structures are divided into five classes including ‘tiny cracks’, ‘slight cracks’, ‘obvious cracks’, ‘severe cracks’, ‘nearly collapsed’. For example, ‘slight cracks’ are described as: cracks with width less than 0.5mm in concrete members, cracks with width less than 1.5mm in masonry members. This type of crack does not have effects on bearing capacity of components.

3.5. Classification of Earthquake Damage to Lifeline Engineering (GB/T 24336, 2009)

Lifeline engineering system is composed of engineering structures, facilities, equipments of different types, etc., of which the evaluation principle of seismic damage levels is as follows: ‘mainly considering damage degree and function loss of structural members, and taking difficult degree of repair into account’. Seismic damage level division standard of lifeline engineering equipment is given, in which lifeline engineering includes traffic system (road, bridge, tunnel, railway line), water supply system (water treatment plant, water supply pumping station, taken water station, pool or water treatment cistern, water supply network), oil transmission system (refinery, oil pump station, oil depot and oil pipeline), gas system (gate station, gasholder, gas transmission pipeline), power system (power plant, substation or distribution station, transmission pipeline), communication system (central control room and communication line) and hydraulic engineering (earth-rock dam).

3.6. Post-earthquake Field Works-Part 4: Assessment of Direct Loss (GB/T18204.4, 2011)

Professor Sun Baitao presided over and completed the work of revising the original standard in 2010. The standard involves the contents, working procedures, computing methods and assessment report format of direct loss assessment of earthquake disaster damage. Based on original standard, the method of loss assessment of seismic damage of constructions considering decoration damage is put forward. In addition, the building proportion considering decoration loss, unit price of decoration reconstruction, damage ratio, difference correction coefficient of economic development and other key parameters are given. Meanwhile, the disaster situation reporting process and reports are established, making assessment of earthquake site damage loss more improved and refined.

3.7. Assessment Methods of Earthquake-caused Indirect Economic Loss (GB/T 27932, 2011)

At present, there are two classes of research method of indirect earthquake economic loss assessment at home and abroad: economic model and empirical statistical model. Take consideration of both scientificalness and operability, the main content of this code includes: Assess the economic losses due to seismic yield reduction and stop production according to the statistical data of actual yield reduction and stop production time and the actual daily mean output value or the reduction of daily mean output value. Assess the regional seismic indirect economic losses according to the statistical relationship between seismic indirect economic losses and direct economic losses. Assess relevance losses of the seismic industry by establishing models based on input-output tables. The content also contains the assessment method of land price losses, direct input for seismic relief, etc.

3.8. Technical Standard for Cost Estimation of Post-Earthquake Rehabilitation of Engineering Structures (GB/T 27933, 2011)

The standard is established based on the direct economic loss assessment results of earthquake site work, fully considering factors such as damage conditions of post-earthquake building structures, structural types of constructions, seismic fortification standard for post-earthquake rehabilitation, post-earthquake price fluctuation, etc. Based on comprehensive analysis of former earthquake rehabilitation planning data, adjustment coefficient matrixes of infrastructure rehabilitation costs could be constructed by research on infrastructure systems (traffic, electricity, municipal facilities, communication, and water conservancy) using statistics analytical methods. Moreover, estimation method, multiplying adjustment coefficients of infrastructure rehabilitation costs by seismic direct economic losses, for various infrastructure rehabilitation costs of different intensity areas was given out. In addition, post-earthquake rehabilitation costs of enterprises could be obtained directly by multiplying estimation results of enterprise seismic loss by adjustment coefficient of post-earthquake enterprise rehabilitation costs estimation.

3.9. Post-earthquake Field Works-Part 2: Safety Assessment of Buildings (GB/T 182.2, 2001)

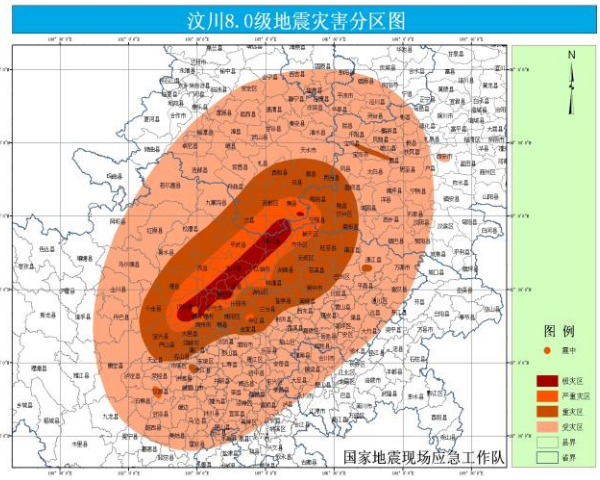
The standard stipulates the principles and methods of safety assessment of buildings on earthquake site after strong earthquakes. The standard is suitable for making safety assessment of shaken buildings subjected to expected earthquake on site during post-earthquake emergency period. However, the standard is not suitable for seismic identification and risk identification for constructions according to seismic fortification intensity requirement at pre-earthquake and post-earthquake. The main contents of this standard including: 1) safety level division method for safety assessment of hit buildings, 2) according to trend of earthquake situation on site, surrounding environment of shaken buildings, damage situation of buildings and other factors, the standard stipulates technical method of safety assessment of shaken buildings on site based on empirical analysis, and general approach of loss assessment for various kinds of structures. 3) Based on aforementioned works, the standard gives out general regulation of safety assessment of buildings at post-earthquake, the allowable damage situation of various safe buildings and safety assessment of buildings subjected to expected earthquake action.

4. LOSS ASSESSMENT OF WENCHUAN EARTHQUAKE AND YUSHU EARTHQUAKE

4.1. Wenchuan Earthquake

At 14:28:04 on May 12th, 2008 (Beijing Time), a great earthquake with Ms=8.0 occurred in Sichuan province (latitude 31.0°N, longitude 103.4°E), which focal depth was 14km, instrument confirming epicenter was located at Wenchuan County in Aba Qiang Autonomous Region. Earthquake affected area included six regions as follows: Sichuan province, Gansu province, Shaanxi province, Chongqing, Yunnan province and Ningxia Hui Autonomous Region, people in nearly thirty provinces (autonomous region or municipality city) of China felt the shaking of this earthquake. According to statistical data cut off on June 4th, this earthquake caused 68,614 people dead, 17980 people missing, 362,085 people injured, and 15,185,800 people homelessness.

The work team of CEA (Yuan, 2008) totally investigated 1,560 residential points (blocks), 546 blocks (communities) in four key cities (Chengdu, Deyang, Mianyang, Guangyuan) and 64 lifeline engineering, 102 enterprises and other industries in 14 Counties (cities, districts). According to the requirement of national standard (GB/T 18208.3; GB/T 18208.4), the affected range was divided into four assessment regions (intensity Ⅵ, Ⅶ, Ⅷ, Ⅸ-Ⅺ) and four city assessment sub-regions, as shown in Figure 1. The shape of whole assessment region is elliptic. The long axis of this region trends NE, and its area is 440,400 square kilometers. The direct economic loss of Sichuan disaster region mainly included losses of houses, engineering structures, relevant industries and enterprises, house decorations, property of indoor and outdoor, etc. The total loss was 519.169 billion, which was 49.42% of Sichuan province GDP in 2007.



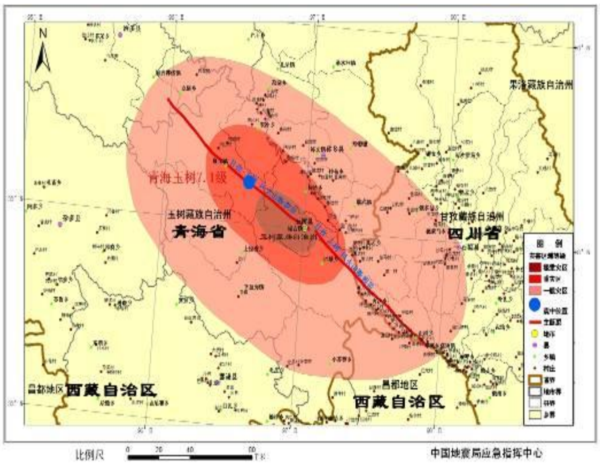


Figure 1. Earthquake disaster assessment region of Wenchuan earthquake

Figure 2. Earthquake disaster assessment region of Yushu earthquake

4.2. Yushu Earthquake

At 7:49:40 on April 14, 2010 (Beijing Time), a great earthquake with Ms=7.1 occurred in Yushu Tibetan Autonomous Prefecture, of which epicenter was located in Jiegu town of Yushu Tibetan Autonomous Prefecture (latitude 33.2 °N, longitude 103.4 °E), focal depth was 14 kilometers, affected area was 35,862 square kilometers, affected population was 246,842. The extreme hit region mainly centralized in Jiegu town, of which area was 900 square kilometers, maximum intensity was up to Ⅸ, while the area of heavily hit region was about 4,000 square kilometers. Cut-off at 18:00 on May 30th, Yushu earthquake had caused 2,968 people dead, 12,135 people injured, 1,434 people severe injured (Chen *et al*., 2010). According to the site survey data, statistical results of lifeline system and industry departments, the disaster region was divided into three assessment regions, as shown in Figure 2, 100 residential points and 10 blocks were investigated. This earthquake-caused direct economic total loss was 12.541 billion, including house loss of 754,630, lifeline engineering and water conservancy facilities loss of 309,400, other industries and enterprises loss of 190,050, while funds for earthquake disaster relief was about 0.2 billion.

5. CONCLUSIONS AND PROSPECTS

After explorations and practices in past more than three decades, the working procedures, methods and standards' system of seismic damage loss assessment with national characteristics has been developed in China, and information management system of earthquake damage prediction in many cities and regions, technical system of earthquake emergency commandment and assessment system of earthquake site losses in continental range have been establised.The research achievements of these systems had already been applied in seismic site works of Wenchuan earthquake and Yushu earthquake with positive impacts, effectively standardizing various site works, providing technical supports and assurance for carrying out seismic site work efficiently, scientifically and in time, which played an important role in the task of earthquake damage mitigation and post-earthquake rehabilitation. However, there are still some problems that need to be improved and perfected further in earthquake hazard loss assessment, following as:

(1) Influenced by the management system of domestic earthquake industry, both earthquake damage prediction system and earthquake emergency response and decision support technology system have been built up in some cities, while neither or none of the sysmtems can be set up in other cities and districts, especially counties, due to financial reasons.. In fact, although the operator interfaces and management forms of these technology systems are different, their basic data, assessment model and many other aspects are interlinked and similar, which should not be divided artificially. Therefore, based on webGIS platform, this paper puts forward the framework of a comprehensive, organic integrated, HAZ-China earthquake loss estimation system (hereinafter referred to as HAZ-China system), which consists of functions of existing earthquake damage prediction, earthquake emergency response and command, earthquake field loss assessment, post-earthquake scientific investigation and rehabilitation. The HAZ-China system can provide comprehensive pre-earthquake, co-earthquake, and post-earthquake information services for different users.

(2) Remote Sensing/Geographic Information System/Global Position System and other new technologies have been introduced in earthquake disaster mitigation, closely combined with the ground observing data and background database, providing disaster mitigation decision-making information and technical support. For example, on May 12th, 2008, a large earthquake with Ms=8.0 occurred in Wenchuan in Sichuan province. Because of large range of earthquake regions and complex situations, deployed prompt disaster assessment,by using earthquake site survey sampling statistical and remote sensing image/aerial photo recognition method had been used in rapid disaster assessment, which saved lot of valuable time for emergency rescue.

(3) The basic theory research should be carried out, for example, suitable module of ground motion attenuation relationship need to be developed in China at present. The analysis methods of infrastructures, new structures and other imperfect methods of seismic vulnerability should be innovated and improved. Both scientific and integrity of basic data should be considered in assessment method. Differences between typical structures and self-built structures, fortication structures and non-fortication structures should be embodied in seismic vulnerability analysis methods.

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