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Study of Assessment Method Based on Coupling Factor of Casualty in Earthquake Disasters in Guangdong Area

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In this paper, the rapid assessment method of casualties in earthquake disasters is studied and a casualty assessment model based on coupling factors is established from the perspective of factors affecting casualties in earthquake disasters. Taking Guangdong area as an example, the spatialization and quantification of casualty coupling factors in earthquake disasters are analyzed in detail. A software system is developed based on ARC Engine 10.1 platform. For the same earthquake case, different algorithms (algorithm model based on coupling factor and algorithm model based on building seismic vulnerability) are used to calculate the number of casualties in order to compare research results.

Keywords: earthquake disaster; casualty assessment; coupling factor; Guangdong Area

1. INTRODUCTION

Guangdong Province is located in the southeastern coastal seismic zone and is one of the provinces with the highest incidence of earthquakes in South China. Over the past 100 years, there have been 11 both moderate and strong earthquakes with magnitudes of 6 or above (including the M7.3 earthquake in Nanao Island, Guangdong in 1908). The Guangdong region currently has a highly developed economy (Liu, W.et al. 2018). Adjacent to Hong Kong and Macao, with special political and economic status, dense population, and low level of urban and rural resistance to earthquake disasters, Guangdong is at a high risk in the event of an earthquake. After a destructive earthquake, it is vital to quickly and accurately assess the scope of impact caused by the disaster and to ascertain the number of casualties so that the emergency rescue command department can quickly make decisions and implement appropriate measures to reduce the losses caused by the earthquake and mitigate its social impact. Therefore, it is especially necessary to devise a new method for the rapid assessment of casualties after earthquake disasters in Guangdong.

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2. ANALYSIS OF COUPLING FACTORS OF CASUALTIES IN EARTHQUAKE DISASTERS

There are two kinds of casualties caused by earthquakes: 1) direct casualties are the deaths, injuries, or disabilities caused by damage to buildings and structures resulting in people being crushed or buried. Indirect casualties are those caused by secondary disasters resulting from the earthquake; these include explosions caused by house collapse, fires, floods, environmental pollution, plague epidemics, and geological disasters such as landslides, mudslides, etc. caused by lifeline engineering and facility damage. Hence, the casualties of earthquake are both human and environmental. Earthquakes of the same size cause different degrees of damage depending on the geographical environment and the economic development of the disaster areas. From her review of previous studies (Xiao Guangxian, 1991; Yin Zhiqian, 1992; Ma Yuhong, Xie Lili, 2000; Fu Zhengxiang, Li Geping, 1993; Cheng Jiayu, Yang Wei, 1993; Wang Xiaoqing et al. 2009; Li Yongqiang et al., 2007; Chen Hongfu et al., 2011), He Ping (2018) analyzed in detail the 184 disastrous earthquakes in China's mainland from 2001 to 2016 (Monitoring and Forecasting Division, China Earthquake Administration, 2010; Monitoring and Forecasting Division, China Earthquake Administration, 2015; Zheng Tongyan, Zheng Yi, 2012 , 2013, 2015, 2016, 2018), qualitatively and quantitatively determining the main factors causing casualties; these factors include the seismic intensity, time of occurrence, population density, degree of building damage, secondary disasters, etc. The analysis results show that the seismic resistance of buildings, population density, degree of urban development and secondary disasters caused by earthquakes are the key coupling factors determining the number of earthquake casualties. Therefore, the focus of this paper is on the development of a rapid assessment method, based mainly on five coupling factors, that can be used to ascertain casualties.

2.1 Building (Structure) Seismic Performance

The seismic performance of buildings (structures) is the most significant factor determining the number of casualties during an earthquake. The collapse, destruction and loss of buildings' utility, caused by an earthquake, have caused serious casualties and economic losses. He Ping (2018) analyzed the correlation between the area of the moderately- and the worse-damaged buildings following the 184 earthquakes that occurred between 2001 and 2016, and the number of casualties caused by each earthquake. The results show that the correlation coefficient between these two variables is 0.999, indicating a highly-significant relationship.

2.2 Population Density and Degree of Urbanization

It can be seen from the history of earthquake disasters that the population density and the degree of urban development in the disaster area are also important factors determining the casualties in earthquake disasters. Urbanization makes the social impact of earthquake disasters more and more diverse, and strongly affects the number of casualties and the amount of economic losses (Wu Guochun, 2012). The 1964 M7.5 earthquake in Niigata demonstrated how urbanization can exacerbate the damage caused by earthquake. The disaster caused by the earthquake and tsunami was made worse by the fires in oil storage, and many buildings were destroyed by the liquid waste that had previously been dumped on the sites. In 1995, the Hanshin M7.2 earthquake was a typical urban-centered underground earthquake. Osaka was the second largest city in Japan. The earthquake caused 5,438 deaths and the direct economic loss was about $100 billion. One of the main reasons for the magnitude of losses was that the earthquake struck the city itself, causing the buildings to collapse and the traffic to come to a halt, paralyzing the city. The other main reason is that the earthquake triggered a very serious secondary fire, caused mainly by the explosion of urban pipeline gas, which added to damage done by the earthquake and increased the number of casualties (China Earthquake Mission to Japan, 1995). On March 11, 2011, the M9.0 earthquake that occurred in Japan was the most serious earthquake in recent years. The earthquake-induced tsunami not only destroyed the villages along the coast, but also affected urban life in Tokyo and other places, and because of the Fukushima nuclear power plant, the problem evolved into a nuclear security crisis, requiring more careful handling.

2.3 Topography

The topographical features of the epicenter largely determine the frequency and intensity of geological disasters after the earthquake, and the magnitude of these disasters also determines the number of casualties. For example, in the southwestern part of China, the natural geographical environment is complex, the geological structure is changeable, the rock is broken into pieces, the mountain area is large, the mountain is high and the valley is deep, and the there are large differences in terrain height. In recent years, most of the devastating earthquakes in the southwestern region have produced secondary disasters such as landslides and mudslides, which have worsened the damage caused by the earthquake itself. The Wenchuan M8.0 earthquake caused 5,094 earthquake-related geological disasters, including 1,701 landslides, 1,866 collapses, 304 mudslides, 1,093 unstable slopes, 21 ground collapses, and 123 ground fissures (Ministry of Land Resources, Earthquake Relief Frontline Command, 2008). In the Zhaotong area of Yunnan, earthquakes of M5.0 or higher usually produce large-scale collapse and secondary disasters, and often result in serious human and animal casualties. For example, in 2006, "7.22, Yanjin, 22 people have died from M5.1 earthquakes"; 81.82% of the total number of deaths were due to collapse of buildings; in 2006, "8.25, Yanjin, M5.1 earthquake killed 2 people", both of them died due to earthquake collapse, accounting for 100.00% of the total; in 2012, "9.7, Yanliang, M5.7, M5.6 earthquake killed 81 people", and 60 people died due to earthquake collapse, accounting for 74.07% of the total number of deaths (Bai Xianfu et al., 2013).

2.4 Site Conditions

The conditions of local sites also have a great impact on the amount of ground movement. The magnitude of the ground movement directly determines the severity of the damage to buildings and structures. Site conditions such as the soil type, the soil thickness, groundwater level and micro-topography factors of the construction site are the main factors affecting the seismic damage. The seismic damage done to weak foundations is greater than that done to strong foundations; the seismic damage to complex sites is greater than for simpler sites (Hu Fengxian et al., 1980). In the 1976 Tangshan earthquake of M7.8, due to the site effect, Tanggu and Hangu in the offshore area of Tianjin were in the VIII degree and IX degree high-intensity anomaly area after the earthquake, and the amount of seismic damage was significantly increased (Liu Huixian, 1986). The earthquake damage was exacerbated by artificial backfilling and gulf soft soil sites in the M7.1 earthquake, in Loma Preta, 1989, the M6.7 earthquake, in Northridge, 1994 (Huang Yulong, 2000), and the M7.3 earthquake in Hanshin Japan, 1995 (China Earthquake Mission to Japan). Local site conditions aggravated the destruction of buildings and structures, thus increasing casualties. In the Wenchuan M8.0 earthquake, it was also found that the seismic damage to the local site in the disaster area of Gansu was obvious, and caused serious damage to the loess area far from the epicenter (Wang Lanmin, Wu Zhijian, 2010).

2.5 Weather Effects

Weather conditions in the disaster areas are also important coupling factors for casualties in earthquake disasters. Severe weather conditions will not only increase the risk of inducing secondary disasters, but also make the disaster worse, and will also have a great impact on post-earthquake rescue. After the Wenchuan M8.0 earthquake, heavy rains in the disaster area caused many mudslides in the middle and high mountainous areas of the hardest hit areas, resulting in more than 450 casualties or missing persons (Wu Weiwei, 2014). In the M9.7 Yanliang "seismic group" earthquake in 2012, although the magnitude of the two earthquakes was not great, the earthquake itself and the heavy rainfall that followed caused large-scale secondary mountain disasters, including 259 landslides, 189 collapses and numerous avalanches (Wang Dongpo et al., 2013).

3. EVALUATION METHOD BASED ON COUPLING FACTOR OF CASUALTIES IN EARTHQUAKE DISASTERS

Since the vulnerability of buildings and structures is the most important factor affecting casualties, the characteristics of building vulnerability should be fully reflected in the algorithm model. In the construction of the assessment method based on the coupling factor of casualties of earthquake disasters, this paper selects the calculation model of casualty based on building vulnerability proposed by Yin Zhiqian (1991), and modifies some parameters according to the data constraints of the emergency basic database as follows:

$$M_D(I) = \rho\,(A_1 r_{d1} + A_2 r_{d2} + A_3 r_{d3}) \tag{1}$$

$$M_H(I) = \rho\quad(A_1 r_{h1} + A_2 r_{h2} + A_3 r_{h3}) \tag{2}$$

Where: $M_D(I)$ is the number of deaths in the affected area when the seismic intensity is I; $M_H(I)$ is the number of serious injuries in the affected area when the seismic intensity is I; $A1$ is the area of the destroyed house; $A2$ is the area of the severely damaged house; $A3$ is the area of the moderately-damaged house; ρ is the percentage of people in the room during the earthquake; r_{d1}, r_{h1} are, respectively, the mortality and serious injury rate in the destroyed house; r_{d2}, r_{h2} are, respectively, the death rate and serious injury rate in the seriously damaged house; r_{d3}, r_{h3} are, respectively, the death rate and serious injury rate in the medium-damaged house;

The model used to calculate casualties based on building vulnerability comprehensively considers three factors: population density, house destruction rate and earthquake time. It is one of the more mature and classic algorithm models. On this basis, and combined with the existing data, some parameters are redefined, and the correction coefficient of the casualty coupling factor is increased under different seismic intensity impact field conditions, to create an evaluation algorithm based on the coupling factor of casualties of earthquake disasters:

$$M'_D = \sum_{I=5}^{n} (M_D(I) \cdot P(I) \cdot T(I) \cdot S(I)) \cdot C \tag{3}$$

$$M'_H = \sum_{I=5}^{n} (M_D(I) \cdot P(I) \cdot T(I) \cdot S(I)) \cdot C \tag{4}$$

Where: P(I) is the population density and the urban development coupling factor correction coefficient when the seismic intensity is I; T(I) is the terrain factor correction coefficient when the seismic intensity is I; $S(I)$ is the site condition correction coefficient when the seismic intensity is I; C is the weather condition when the seismic intensity is I disregarding the differences in weather in different seismic intensity zones, except for the weather in the extreme earthquake zone; M'_D is the number of deaths caused by the earthquake; M'_H is the number of seriously injured in the earthquake .

4. CHARACTERISTICS OF DISASTER-BREEDING ENVIRONMENT IN GUANGDONG

In order to better explain the application of the coupling factor-based seismic casualties assessment method and the selection of model parameters, the Guangdong area is used to analyze the disaster-conducive characteristics of the environment of the area, and to spatialize and quantify the coupling factors of earthquake casualties.

4.1 Topographic Features

Guangdong Province is located in the southernmost part of mainland China, with a land area of 179,800 km^2. It is bordered by Fujian in the east, Jiangxi and Hunan in the north, Guangxi in the west, and the South China Sea in the south. The eastern and western sides of the Pearl River estuary are bordered by the Hong Kong and Macao Special Administrative Regions respectively. The Leizhou Peninsula in the southwest is across the Qiongzhou Strait and Hainan Province.

The complex terrain of Guangdong is high in the north and low in the south. The area consists mainly of mountains and hills, although there are also basins and plains. The mountain area accounts for 31.7% of the province's total area, the hills account for 28.5%, the basin accounts for 16.1%, and the plains account for 23.7%. The mountains in the territory are found mainly in the north, east, and west of Guangdong. Most of

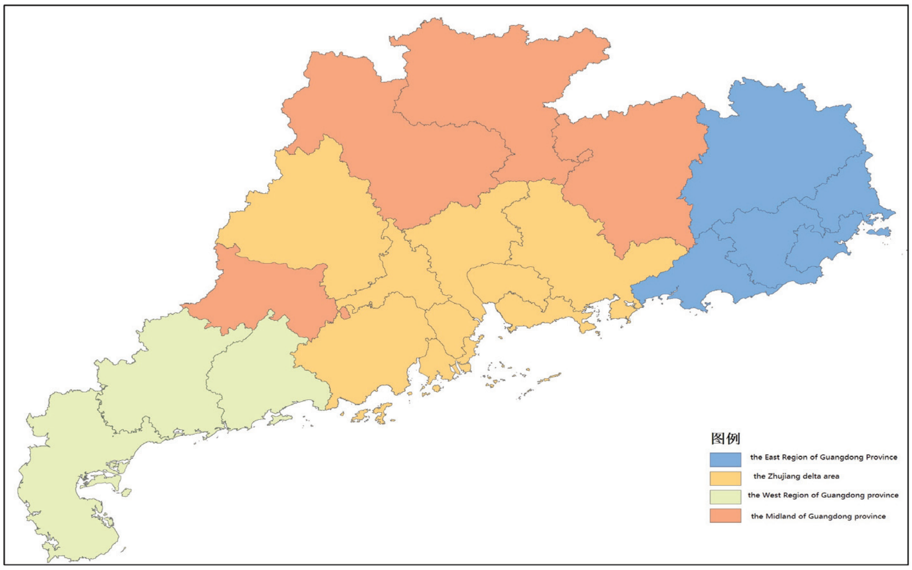


Figure 1 Diagram of spatial distribution of regional economic development differences in Guangdong Province

them follow a NE-WS direction. The plains mainly include river valley alluvial plains and delta plains. The valley alluvial plains are intermittently distributed along the shores of various rivers. The main delta plains are the Pearl River Delta and the Hanjiang Delta. The hills are mostly distributed around the mountains, or scattered along the coastal plains and terraces, with an altitude of 200–500 m.

4.2 Characteristics of Population and Regional Economic Development

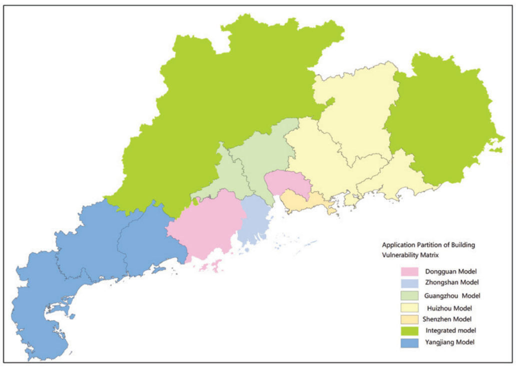
The geographical and topographical characteristics of the Guangdong area account for the significant regional differences in local population and economic development. The province's average population density is 621 people/km^2, ranking fourth in the country. However, the population density varies greatly. The majority of people have settled on the Pearl River Delta and on the Chaoshan Plain where the local population density can reach 10,000/km^2, and on the southwest coast where the population density is above 1,000 people/km^2. The population density in mountainous area in the north of Guangdong is between 200 and 500 people/km^2. There are also significant differences in the economic development of the various regions. The highest level of economic development and urban industrialization is in the Pearl River Delta region comprising the nine prefecture-level cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen and Qiqing. The east and west of Guangdong have medium-level development and industrialization, and include the four prefecture-level cities of Shantou, Shanwei, Chaozhou and Jieyang. 4. In the western region of there are the three prefecture-level cities of Yangjiang, Zhanjiang and Maoming. The northern mountainous areas of Guangdong include Heyuan, Meizhou, Shaoguan, Qingyuan and Yunfu, which are five prefecture-level cities. Their natural environment, resources, social science and technology, infrastructure and other aspects are less developed (Sang-Bing Tsai et al. 2016). They are also areas in Guangdong where there is a concentration of people living close to or below the poverty line, as shown in Figure 1.

5. SPATIALIZATION AND QUANTIFICATION OF THE COUPLING FACTOR OF POPULATION CASUALTIES IN EARTHQUAKE DISASTERS

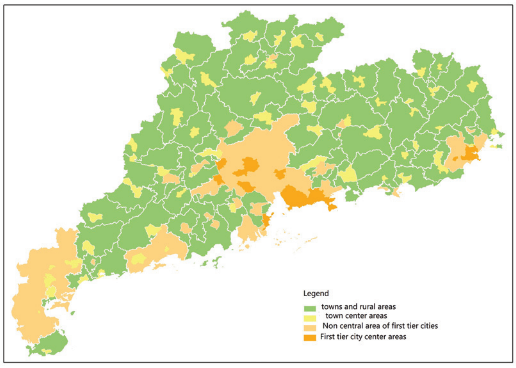
The complex disaster-conducive characteristics of various environments in Guangdong make it unfeasible and unscientific to quantify the coupling factor of the casualties of earthquake victims throughout the whole area by using fixed data. It is necessary to spatially partition the coupling factor itself and then quantify it.

5.1 Building Damage Vulnerability Factor B

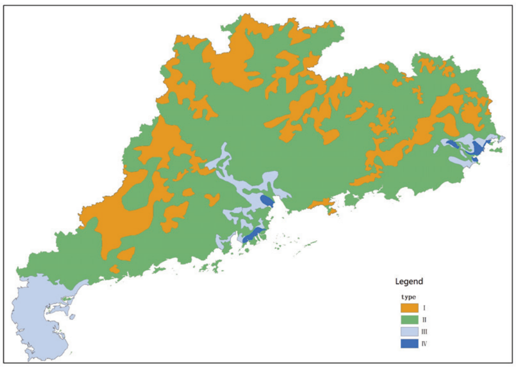
Due to the great differences between regions in terms of customs and levels of economic development, there are regional differences in the seismic capacity of buildings. It can be seen from equation (1) that for the assessment of casualty, the vulnerability matrix of the building is a very important calculation parameter, so the localization of the matrix is very important (Li, C. et al. 2016). At present, only seven cities have completed the seismic damage prediction project in Guangdong Province: Guangzhou, Shenzhen, Dongguan, Zhongshan, Zhuhai, Yangjiang and Huizhou. According to the local site characteristics and level of economic development, cities that have not made earthquake predictions are matched, as shown in Figure 2(a).



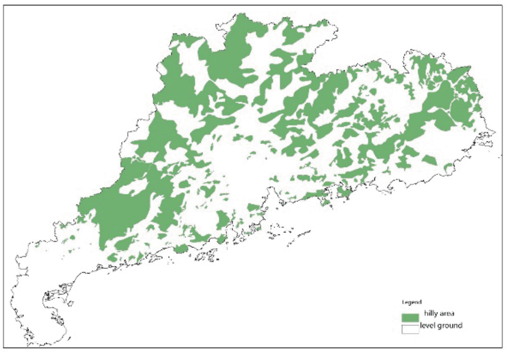
(a) spatialization diagram of building vulnerability impact factor



(b) spatialization diagram of population density and urban development impact factor



(c) spatialization diagram of building site condition impact factor



(d) spatialization diagram of terrain impact factor

Figure 2 Spatialization and Quantification Diagram of the coupling factor of the casualties of earthquake victims in Guangdong Province

5.2 Population Density and Urban Development Degree Impact Factor P

In order to better quantify the population density of Guangdong and the degree of urban socialization, the development level of the urban population, the economy and the urbanization is classified under four categories (Fig. 2b): the central city among the first-tier cities; cities based mainly on non-central areas of the urban area and the first-tier cities; the district and county central urban areas and urban central areas; townships and rural areas. Using data for the 184 earthquake cases (Monitoring and Forecasting Division, China Earthquake Administration, 2010; Monitoring and Forecasting Division, China Earthquake Administration, 2015; Zheng Tongyan, Zheng Yi, 2012, 2013, 2015, 2016, 2018; Wen Xintao, 2018), He Ping, (2018) quantifies the impact of population density and urban development on the magnitude of earthquake disasters. These four types of areas are assigned different weights (3.0, 2.0, 1.0, 0.6, respectively) when calculating the casualty loss, to distinguish the different degrees of impact that the earthquake would have in the area.

5.3 Site Condition Impact Factor S

The terrain of Guangdong is high in the north and low in the south. Many rivers flow into the sea in the south. Due to the influence of temperature and humidity, there is severe weathering of continental debris, and the frequent storms and rains have increased the surface erosion. The water current is stronger and has led to the accumulation of deep mud and sand in coastal areas. The weak foundations of buildings combined with a high groundwater level is an unfavorable factor that can aggravate the seismic damage. According to the "Code for Seismic Design of Buildings" (GB50011-2010), and referring to the previous research results obtained by the earthquake agency of Guangdong province, the existing sites are roughly divided into four categories. The spatial distribution of the sites is shown in Figure 2c, and the impact of site types on the magnitude of earthquake disasters is quantified. Different site types are assigned different weights when calculating the casualty loss. The coupling factor S is 0.5, 1.0, 1.2, 1.5 under different site conditions.

5.4 Terrain Impact Factor T

Although the mountains in the hilly platform of Guangdong are not high, if the epicenter is in the mountainous area, it will cause small landslides and landslides. For example, the "mountain stripping" phenomenon after the Heyuan M6.1 earthquake in 1962, could also worsen the earthquake damage in mountainous areas. Therefore, it is necessary to divide the existing Guangdong topographical impact factors (Fig. 2d). A digital elevation map of Guangdong was used to distinguish the mountainous area of Guangdong from the flat land is extracted, and the data was applied in the calculations. However, most of

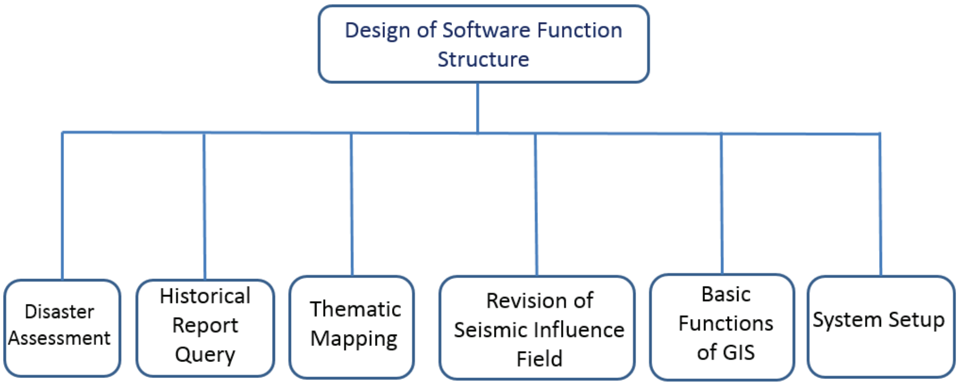


Figure 3 Software Functional Structure Design

the earthquake landslides in Guangdong Province are light or confined to small areas. It is impossible to have landslides with a certain scale and great influence like those in the southwestern region. Moreover, the landslides after an earthquake are more affected by the climate, so it is also necessary to consider the possibility that the landslides occur during or after heavy rainfall. Combined with the author's research on of 184 earthquake cases (He Ping, 2018), the T coupling factor has a value of 1.1 in the mountainous area (the coefficient increases to 1.5 after heavy rainfall) and a flat value of 1.0.

5.5 Weather Impact Factor C

Meteorological disasters are the most common natural disasters in Guangdong. The disaster period is long, and the annual losses account for more than 90% of the total losses. The historical earthquake cases show that the occurrence of earthquakes is often accompanied by extreme weather. Severe weather will magnify earthquake disasters and increase the risk of earthquake-induced secondary disasters, thus causing more casualties and rapidly increasing economic losses. Hence, when disasters occur, the weather conditions in the disaster area must be monitored and heeded. However, according to the current information on earthquakes, it is difficult to make quantitative comparisons of earthquakes with the same magnitude due to different weather conditions, and it is difficult to quantify the impact of weather effects. Therefore, when the assessment software is developed, the weather is expressed only as an additional input variable, but not a normal parameter.

6. ALGORITHM IMPLEMENTATION

In this paper, the system development uses Microsoft's integrated development environment Visual Studio 2010, Visual Studio 2010, which provides an efficient and integrated development environment for design, coding, debugging and testing in a unified environment. The development language adopts C#, and the lay-out development adopts Microsoft's WPF+Ribbon, which can make the interface function organized, and its rich command layout makes it easier for users to find the required functions (He Ping, 2018). The GIS platform uses ESRI's ArcEngine 10.1. ArcEngine 10.1 is a fully componentized GIS platform that provides a rich, powerful, basic development interface that includes data processing, spatial analysis, map browsing, and mapping.

In the actual calculation, the space and attribute data of the five coupling factors above are saved into a parameter database, so that the assignment can be directly called to achieve the practical application of the algorithm. In the software design, the pre-assessed calculation of the seismic damage and the output of the related report are considered. At the same time, the automatic output module of the thematic maps with more applications is also given, which is convenient for users. Figure 3 shows the overall architecture of the system.

In order to better compare the pre-assessed results, the choice to adopt the personnel coupling factor casualty algorithm is made in the input seismic parameter window. The default is based on the algorithm model of the vulnerability of buildings and structures. The vulnerability matrix of the building is uniformly applied throughout the province; after checking, it can be pre-assessed according to the coupling factor-based casualty algorithm (Fig 4). The first two algorithms can obtain an assessment report, which is convenient for comparison purposes. In this paper, several earthquakes in the history of Guangdong Province were evaluated for seismic damage. The calculation results are shown in Table 1.

7. CONCLUSIONS AND DISCUSSION

In this paper, the coupling factors affecting casualties in earthquakes are the seismic performance of buildings, the population density and degree of urban development, site conditions, topography, and weather conditions, which are taken as important parameters to establish an earthquake disaster casualty assessment model based on multi-coupling factors. In order to estimate the number of earthquake casualties, this study examined five earthquakes in the history of Guangdong, and subsequently proved that the proposed assessment method model is feasible. The calculated number of casualties showed obvious regional differences as expected, and the theoretical calculation results are well-aligned with the actual situation. However, in the actual application of the algorithm, the following problems exist, which will be addressed in future research.

(1) Due to technical limitations, the quantitative value of the coupling factor is selected in the software according to

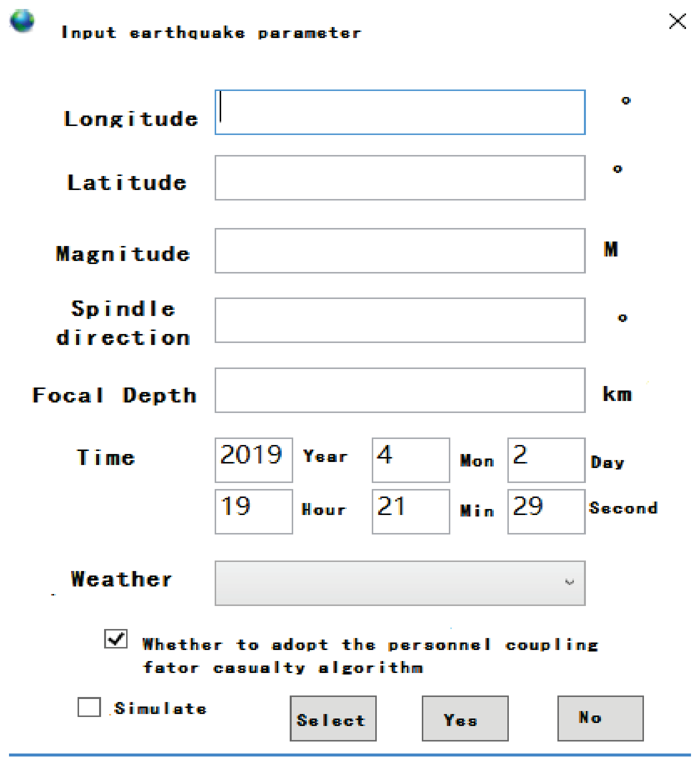


Figure 4 Diagrammatic Sketch of Algorithmic Selection in Software.

Table 1 Comparisons of two evaluation algorithms.

Earthquake event	Magnitude	$\varphi_N(°)$	$\lambda_E(°)$	Historical earthquake damage (Guangdong Provincial Local History Compilation Committee, 2001)	Algorithm1		Algorithm 2	
					Number of deaths	Number of serious injuries	Number of deaths	Number of serious injuries
Four years of the Chaozhou area in Northern Song Dynasty	6.8	23.65	116.6	The earthquake with an epicenter intensity of IX degree has serious casualties and property losses	1 680	7 150	1 135	4 814
Earthquake in Nanao island, 1908	7.3	23.5	117.2	The epicenter area was in the area of Quanzhou to Shantou, The ground cracked and collapsed, the sea water poured, and the house was overturned with hundreds of casualties	310	1 453	756	3 436
Jieyang	6.0	23.5	116.5	150 meters 6 feet city walls, 1059 rooms collapsed. 55 people were killed and 14 people were injured.	170	751	314	1 376

the superposition analysis of the spatial distribution of the seismic intensity and the coupling factor. The proportion determines the specific parameters of the coupling factor. It is therefore difficult to avoid errors with different coupling factor values at the same intensity.

(2) A comparison of the results for the various cases shows that the number of casualties assessed by the earthquake disaster casualty assessment algorithm model based on multi-coupling factors has obvious regional differences. An earthquake of the same magnitude can produce significantly different damage and casualties due to the differences, both social and environmental/geographic, between various disaster areas. However, due to the long history of earthquakes in Guangdong, the location of many historical earthquakes is not accurate so that it is difficult to compare the historical seismic damage characteristics with the current disaster-conducive environmental characteristics, and it is difficult to verify the accuracy and reliability of the algorithm. In future, when designing the algorithm model,

Table 1 Comparisons of two evaluation algorithms(Continued)

Heyuan Earthquake in 1961	6.2	23.73	114.67	Two people died in the earthquake-stricken area, seriously injured and 29 people slightly injured. The four communes in Chengguan Town, Dongpu, Xiantang and Puqian, which suffered from severe disasters, totaled 20,448 houses collapsed, 5 people died and 60 people were injured.	145	667	273	1 242
Yangjiang Earthquake in 1969	6.4	21.7	114.7	The earthquake killed 33 people and injured 1,000 people and caused ground fissures, sand blasting, water rushing and rock fragmentation, and it was regularly distributed.	110	1 863	232	2 356

a more scientific approach would be to study and compare multiple seismic areas.

(3) The generalizability of the value of the coupling factor requires further analysis. Although from the historical earthquake cases, the specific coupling factors affecting casualties can be obtained macroscopically, the accuracy of the specific values of the coupling factors depends on the accurate analysis of the earthquake cases, which is limited by the current lack of data and makes it difficult to achieve an acceptable level of accuracy. Only by continuous debugging, can more accurate results be obtained.

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