A Seismic Multi-Level Hybrid Grid System for Post-Earthquake Loss Assessment

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***Abstract* — Timely and rapid assessment of post-earthquake loss is important to mitigate earthquake disaster. In practice, however, earthquake related data are complex and spatial heterogeneous, making it difficult to evaluate the earthquake disaster quickly and accurately. It is very necessary and urgent to construct a platform to prevent and mitigate earthquake disaster. Compared with the existing earthquake data management methods, which assume the data are distributed evenly in the whole area, this paper proposed a seismic multi-level hybrid grid system (SMHGS). The core idea of SMHGS is using multi-level spatial hybrid grid to manage the earthquake related data and fully consider the spatial heterogeneous of these data. With SMHGS, the efficiency of data management is improved. The proposed approach was exemplified in Yushu earthquake (Ms 7.1) in China in 2010. The case applications show that the SMHGS can effectively manage and analyze massive earthquake data. As the system has run very stably, it can be recommended to a national level of China.**

Keywords - seismic multi-level hybrid grid system (SMHGS); spatial heterogeneity; earthquake; economic loss assessment; GIS

I. INTRODUCTION

Earthquake is a sudden natural disaster that seriously endangers the safety of people's lives and property. China is one of the countries where earthquake disasters occur most frequently and the damage are most serious. However, at present, humans haven't accurately predicted each earthquake so far. Therefore, rapid and accurate assessment on earthquake disaster after earthquake is an effective way to reduce the risk of disasters and is also a foundation of post-disaster rescue.

Gestation and occurrence of earthquake is very complex. It relates with many multi-source and spatial heterogeneous factors, which making the quick and accurate loss assessment to be difficult. Effective storage and management of these data is the assurance for rapidly and accurate loss assessment after an earthquake. At present, GIS-based method is widely used to manage these earthquake related data. The GIS-based method usually uses the administrative unit-based data, which regards an entire administrative area as the stricken region and assume the exposure data are evenly distributed in the whole region. However, earthquake related data are changed from area to area. Usually, erroneous evaluation result may be obtained and inappropriate rescue decisions may be implemented when exposure data of an entire administrative area is used [3].

The earthquake related data not only have various structures and types, but also have intrinsically dynamic and spatiotemporal characteristics. To effectively manage these data and get the disaster loss timely and accurately, this paper proposed a novel seismic multi-level hybrid grid system (SMHGS) for post-earthquake loss assessment. Seismic multi-level hybrid grid (SMHG) is a thematic spatial information grid (SIG) for earthquake. Hybrid grid has the advantages of both administrative grid and regular grid. It fully considers the spatial disparity of disaster exposure data and tries to provide a new scientific and reasonable way to deal with the acquisition, intelligent storage, integrated management and statistical analysis of earthquake spatial data and evaluated the post-earthquake casualty timely and accurately. This paper is organized as follows. In section 2, the classification and characteristics of the earthquake data and the data management method based on SMHGS is discussed. In the section 3, framework of SMHGS is represented. In the section 4, the implementation and applications of SMHGS are represented. Section 5 concludes the paper.

II. EARTHQUAKE DATA

A. Classification of Earthquake Data

In general, earthquake data can be divided into three types: 1) earthquake thematic data, 2) general geographical data, 3) other data related to earthquake.

1) Earthquake thematic data

Earthquake thematic data mainly include magnitude, intensity, occurrence time, epicentral distance and focal depth. Earthquake thematic database is composed of earthquake history database and real-time database. The real-time database is docked with China Earthquake

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Networks Center (CENC), responsible for collecting the latest seismic data. The real-time data is a kind of raw-data, which is a series of records detected by CENC and stored in real time database. With the help of inspection and calibration, the ripe data can be obtained and will be stored in the history database.

2) General geographical data

General geographical data mainly contain fundamental geographical and thematic information relevant to the serving objects. The former involves basic geographical features, including traffic lines (e.g. high-speed road, railroad), key river systems, administrations that contain administrative boundaries, local government and residential areas, as well as other public infrastructures. The latter is concentrated on the construction of different professional spatial distributed maps (e.g. fault zone and seismic zone distribution map) for thematic geological businesses.

3) Other data related to earthquake

To further broaden the application of earthquake spatial data, other social economic data, secondary disaster data and emergency rescue relevant data can be added to the study. The social economic data main contain the loss assessment related population, building, economic and lifeline data. The damage caused by an earthquake not only has direct influence factors, but also has indirect influence factors. Secondary disaster is the most important indirect influence factors of earthquake. The mainly secondary disasters are fires, landslides, tsunamis and so on. The emergency rescue relevant data are those medical rescue data, the traffic condition data and so on. All these data are necessary to the evaluation of an earthquake.

B. Characteristics of Earthquake Data

Earthquake occurs dynamically both in time and space. The characteristics of seismic data are as follows.

1) Multi-source and complex data types

Earthquake is closely related to many factors no matter in the cause or in the assessment after the disaster. Earthquake thematic data, general geographical data and other related data are all the influence factors for an earthquake. The relevant data come from different sources and have different types. Therefore, the seismic data are massive and complex in both structure and storage. The earthquake thematic data are also updated in real time. Hence, the total amount of earthquake data is enormous.

2) Time and spatial heterogeneity

Earthquake occurs dynamically in time and space. The spatial distribution of seismic activity is complex and random. The distribution and occurrence of earthquake has a spatial heterogeneity. Different tectonic zone has different earthquake thematic data and various attribute data. Moreover, earthquake disaster risk is different from area to area. To ensure the accurate and effective of the loss assessment of earthquake, the earthquake detecting data and the relevant dynamic data need to be fed back into the earthquake spatial database and updated real time. In fact, the spatial dynamic and time sensitivity of earthquake data is very obvious.

C. Earthquake Data Management Based on SMHG

Above all, the earthquake is influenced by kinds of factors and the related data are multi-source and complex. It changes from area to area. To quickly and accurately assess the earthquake disaster loss, effective management and fully considering about the spatial heterogeneity of the earthquake data is necessary. Given the earthquake related data containing lots of spatial data, it is unable to use the single relational database to store these data. At present, GIS-based method is a popular method used in earthquake data management. By using the spatial database, the GIS-based method can effectively manage the earthquake spatial data. However, this method considers the whole area as the stricken region and assumes the exposure data in the stricken region to be evenly distributed within the entire area. In fact, the intensities and the social economic data are different from area to area.

To address this problem, multi-level spatial information grid is introduced into this paper. SIG integrates a variety of spatial information technology, and can organize and manage spatial data in grid. SIG has been applied in various disaster assessment models and was shown to be able to improve the result accuracy by considering the spatial disparity of disaster exposure data. SMHG is an earthquake thematic spatial information grid, which is specially used for earthquake loss assessment.

In general, SIG can be categorized into two types: irregular grid and regular grid. Irregular grid is often based on administrative units, which make it convenient for the relevant administrative departments to manage disaster and make rescue strategy. In this paper, the irregular grid main contains regional grid, provincial grid and county grid. Regular grid is composed with a series grid with same size and shape. It assumes the exposure data evenly distributed in the grid unit. However, both irregular grid and regular grid assume the exposure data are not changed in the internal grid. It is still cannot fully express the spatial characters of various earthquake data. To settle this problem, a novel hybrid grid is proposed in this paper. The hybrid grid format map is generated by overlaying the isoseismal map, county grid format map and a regular grid format map. In hybrid grid, the former irregular grid or regular grid is divided into several sub-grids. The sub-grids are hybrid grids with irregular and regular shapes and sizes. Generally, under the same area, the hybrid grid can express the exposure data more accuracy when the number of the grid is more.

In the proposed SMHG, a whole area is divided into grids at different levels with different sizes. Earthquake related data are stored in different levels of the grids to improve data management efficiency. Fig.1 shows the types and contents of SMHG.

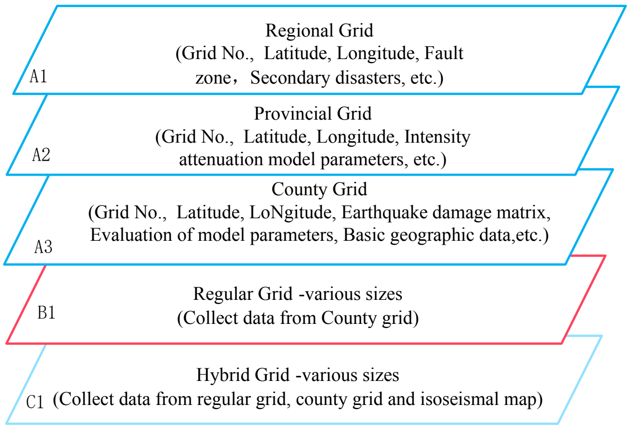


Figure 1 Types and contents of SMHG

III. FRAMEWORK OF SMHGS

A. Aims of the SMHGS

Based on SMHG, a seismic multi-level hybrid grid system (SMHGS) is built. SMHGS is integrated application information system for earthquake loss assessment. It is aims to provide a platform for the acquisition, storage, management, analysis, application and service of earthquake data. This kind of system will meet the demands of society for earthquake information and be very useful for providing emergency disaster information for rescue decision-making.

There are three key specific objects of the proposed SMHGS. The first object is to build a seismic multi-level hybrid grid system. It can realize the grid construction, grid-based earthquake data collection and acquisition, data organization and storage, and data query and service. The second object is to evaluate the earthquake loss based on SMHGS. The proposed SMHGS should be combined with assessment models to evaluate the human loss, economic loss, building loss and other loss in earthquake event. The third object is to analysis and visually display the evaluation results. By using the statistical analysis of the evaluation results, provides data support for the government to determine the corresponding post-disaster emergency rescue strategies.

B. General Design of the SMHGS

In order to achieve the above goals of the proposed SMHGS, the whole architecture is classified into four tiers. These tiers are data collection tier, data management tier, grid management tier and loss assessment tier (Fig.2).

The data collection tier is responsible for collecting earthquake thematic data from CENC, some related raw data, which are sent to the SMHGS by a communication network. After processing of the raw data, the collected data are classified and stored in the spatial database. Seismic multi-level hybrid grid platform is an intermediate management platform. To the bottom, it is connected to the database. To the upper layer, it provides data support for the application layer. The top layer is the application layer, which is responsible for earthquake loss assessment and result analysis. The system architecture is shown in Fig.2.

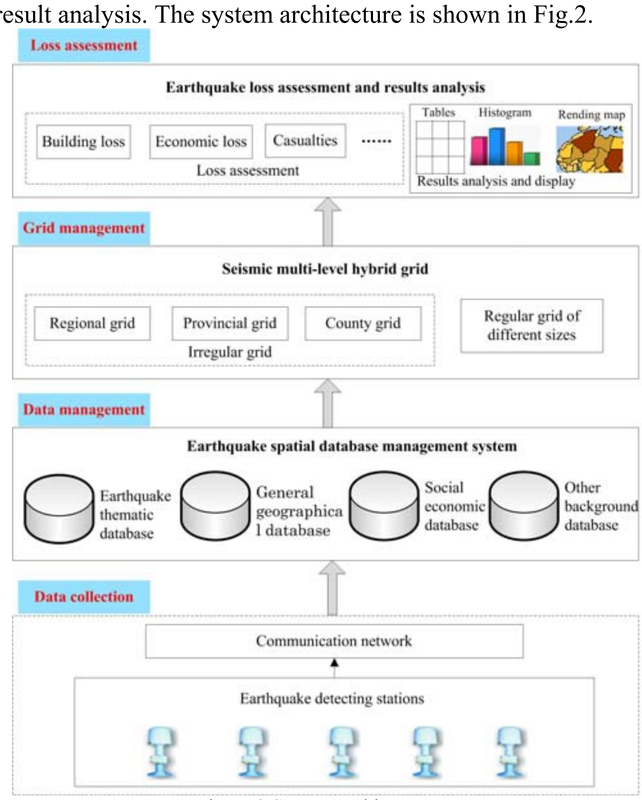


Figure 2 System architecture

C. Main Function Modules of SMHGS

Based on the designed system architecture and system requirements, the basic functional modules can be summarized as follows (Fig. 3). It can be divided into five parts: 1) Input / output interface module. It is responsible for the input and output of the earthquake related data and result data. 2) Layer management. It is responsible for management of the map data. 3) Grid platform. It is the basic grid platform, which contains the grid construction, data collection, data query and data storage based on the grid. 4) Applications of SMHGS. It is the part of the earthquake loss assessment based on SMHGS. 5) Result analysis and export. It is mainly about the analysis of the evaluation result and export with table, rendering map and so on.

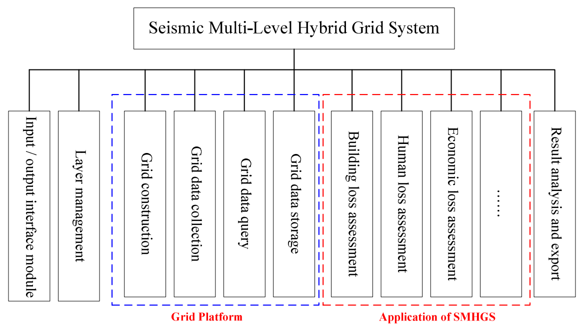


Figure 3 Functional structure of SMHGS

IV. IMPLEMENTATION AND APPLICATIONS OF SMHGS

A. Key Technologies of the Implementation

1) Multi-level grid construction and coding oriented to earthquake

Grid construction and coding is one of the key technologies of SMHGS. The complete spatial information grid is composed of many thematic spatial information grid systems in different application fields. Seismic spatial information grid is a thematic SIG for earthquake. It takes earthquake data as the processing object, and studies the type, scale, data model and grid coding technology of seismic spatial information grid. The type and scale of SMHG has been discussed in section 2. In this section, we focus on discussing the data model and grid coding technology of SMHG.

The earthquake related data contains both vector data and raster data. To effectively manage the earthquake data, a special data model is necessary. Geodatabase model, which is a typical object oriented data model can realize the unified storage and management of raster, vector and other data formats, and support a variety of relational database platforms. It can express the world in a more realistic way. Therefore, geodatabase model is selected as the data model in SMHGS.

In SMHGS, quickly and efficiently retrieve data need to a set of proper grid coding mechanism. The grid coding technology is to study a coding model and provide a unique identification code for every grid. Given the multi type and multi scale of seismic spatial information grid, the paper proposed a variable length coding model for SMHG and named it as SMHG-ID. In SMHG-ID, there is only one bit code for the regional grid. For the provincial grid, three bit codes are needed. The first code is the ascription region, and the last two codes are the provincial information. For the county grid, seven bit codes are needed. The first three codes are the same as provincial grid, and the last four codes are for county information. For the regular code, coordinate of the grid center point (x, y) are used to identify the regular grid. Variables of x and y are two variable length floating data. For the hybrid grid, eleven bit codes are needed. It is composed with regional code, provincial code, county code, regular grid code and intensity identification code.

The universal model formula of SMHG-ID can be expressed as:

$$Code = Q\ S_0 S_1 X_0 X_1 X_2 X_3 G_0 G_1 \mathrm{I} \qquad (1)$$

Where, Q is the regional code. S_0 and S_1 are the provincial codes. X_0, X_1, X_2 and X_3 are the county codes. G_0 and G_1 are the regular code. I is the intensity identification code.

2) Storage and security technology of massive spatial data

Earthquake related data come from multi-source and have complex types. These data have typical features in space, attribute, topology and time. As the quantity of these data reaches TB level, manage these massive data brings a great challenge to the storage and security.

To management the massive spatial data simply depend on traditional relational database is not enough. The combination of spatial data engineer of ArcGIS (ArcSDE) and SQL server has shown tremendous advantages in spatial data storage. For the data conflict and security, version control mechanism, automatic recovery and backup mechanism are used to ensure the database security. Moreover, in SMHGS, the combination management of the spatial data based on ArcSDE and SQL server is the bottom management of earthquake related data. On the upper layer, multi-level grid is used to manage the data. Different data are stored in different level of the grid, which will further improve the efficiency and security of data access.

3) Spatial analysis of the earthquake spatial data

SMHGS is composed of lots of layers and each layer contains rich information. The data between the layers and in the internal layers have a complex relationship. Therefore, to analyze the spatial and attribute data in the grid layer and find the deep relationship between these data, spatial data analysis technology is essential.

Spatial analysis technology uses algebra, geometry, logic and other mathematical methods to excavate the deeper internal characteristics of the spatial data and the potential relationship between these data. At last, it expresses the analysis results in the way of new knowledge for the deciding makers. According to the evaluation and rescue processing, the spatial analysis technologies used in this study are the overlaying analysis, buffer analysis and network analysis. The overlaying analysis is mainly used in the grid data acquisition, the epicenter location and evaluation layers overlaying. The buffer analysis is mainly used for the disaster influence range calculation. The network analysis is mainly used for calculating the best rescuing path.

B. Application in Economic Loss Assessment

In SMHGS, earthquake related data are hierarchically stored and managed in different level grids. The evaluation process is closely connected to this hierarchical grid system. In this evaluation approach, map can be divided into three categories: hazard map, exposure map and impact map. Hazard map is the distribution map of earthquake disaster. Exposure map is used to store exposure data, such as population density, building data, model parameters and so on. The county grid, all regular grid and irregular grid can be regard as exposure map. Impact map is the result map that can give the evaluation result of post-earthquake casualty.

The whole evaluation processing can be divided into four stages. The first stage is to construct the earthquake database and then generate the exposure map in grid format. Secondly, getting parameter data from provincial grid and regional grid, and then generate the hazard map according to the intensity attenuation model. Thirdly, get the exposure data in different intensity zoning by overlaying the hazard map and exposure map. Then evaluate the disaster loss under the evaluation model. Finally, the impact map is generated and the result analysis can be done based on the impact map.

Yushu earthquake (Ms 7.1) in China in 2010 was selected as a case study to validate the proposed method. In this study, we take the economic loss assessment as an example. To get the economic loss, a hazard map and an exposure map should be obtained first. In an earthquake, the seismic isoseismal map is a kind of hazard map. So we first draw the seismic isoseismal map of Yushu earthquake. The exposure map carries the exposure data. In this study, the exposure data come from China statistical yearbook for regional economy in 2010 and the 6th census data in China. Based on these data and the above evaluate method, the impact map of Yushu earthquake can be obtained. With the attribute table of impact map, the economic loss in Yushu earthquake in different countries can be calculated as follows (Table 1).

TABLE 1: Economic loss in Yushu earthquake in different counties

County	Intensity	Total economic loss (ten thousand RMB)	Per capita economic loss (1 RMB/person)
Yushu	9/8/7/6	176830	4858
Zhiduo	7/6	7674	3837
Chengduo	7/6	23190	3681
Qumalai	6	1623	768
Shiqu	6	9620	962
Zaduo	6	2622	874
Nangqian	6	1916	658
Shengda	6	9974	758

In SMHGS, the evaluation result can be displayed in different ways. Except the statistical table like table 1, linear statistical figure and rending map are the optional ways (Fig.4 and Fig.5).

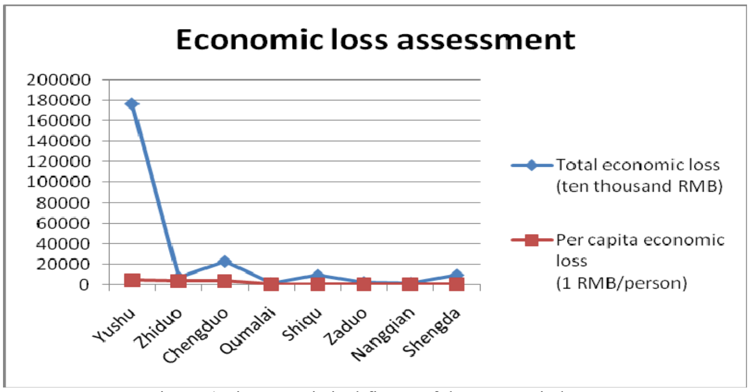
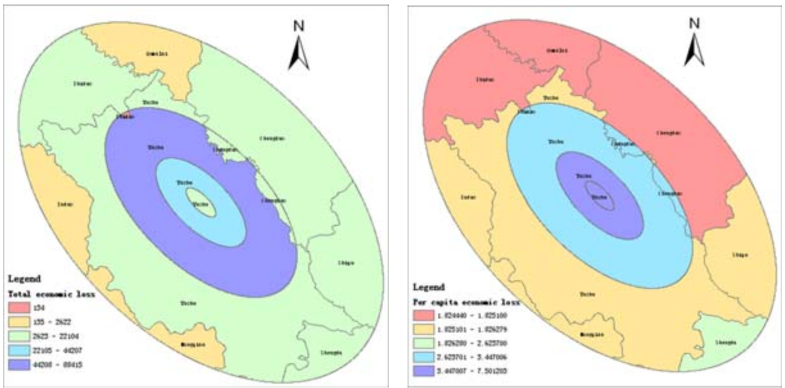


Figure 4 Linear statistical figure of the economic loss



(a) (b)

Figure 5 (a) Impact map rendering by total economic loss; (b) Impact map rendering by per capita economic loss

From the above statistical data, we can conclude that the economic in Yushu County is most serious. The main reason for this is that Yushu County covers four seismic intensity regions, particularly containing the two highest intensity regions, which are not covered in other counties. However, in the highest intensity region of Fig.5 (a), the total economic loss in the epicenter is not the highest because total economic loss is also related to total area, population number and other influencing factors. By contrast, in Fig.5 (b), the per capita economic loss in a higher-intensity region is higher than in a lower-intensity region.

Overall, the evaluated results express the severity of economic loss after an earthquake, respectively. What's more, based on the hybrid grid, results can be displayed in grid unit, which provides a spatial distribution of possible loss of earthquake disaster. This will be helpful to earthquake response rescue services and rescue evacuation.

V. CONCLUSIONS

Timely and accurate evaluation of earthquake loss is an effective method for emergency rescue actions in the gold 72 hours after earthquake. A novel seismic multi-level hybrid grid system for post-earthquake loss assessment was successfully performed in this paper. The multi-level hybrid grid has shown its tremendous advantages in massive spatial data storage and the multi-source and complex earthquake data management. Meanwhile, spatial information grid, especially the hybrid grid, fully considered the uneven distribution of temporal and spatial distribution of exposure data, which was greatly improving the accuracy of assessment.

Yushu earthquake was selected as a case study to validate the novel method. The result shows that evaluation based on SMHGS is effective and feasible. As the system has run very stably, it can be recommended to a national level of China.

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