Comprehensive Isoseismal Map of North China Active Block Area

Lyu Yuejun, Sha Haijun, Liu Jingwei, Xie Zhuojuan, Zhang Lifang

Institute of Crustal Dynamics, CEA

Abstract

The comprehensive isoseismal map shows the maximum intensities of the earthquakes in an area for the period, which provides important information for people to understand earthquake spatial distribution, earthquake strength, geological structure, seismic influence, etc.

In this study, we took the North China Active Block Area as the research area, and produced a comprehensive isoseismal map of North China, which provides a basis for the assessment of seismic hazard in North China. We collected all data of earthquakes greater than M4¾, including whose epicenter located in the study area, and those produced the affecting intensities greater than V for the area. We digitized isoseismal map of every historical earthquake if it had and built a database using ArcView software. Taking advantage of the function of data management and drawing, we obtained the comprehensive isoseismal map for North China.

The several conclusions can be obtained and listed as follows.

1. Since 1484, 80 percent of areas have experienced intensities greater than Ⅵ in North China.

2. Intensities greater than Ⅶ widely distributed with band, mainly along Huashan front fault, Fen-Wei fault depression zone, Tanlu fault zone, and Zhangjiakou-Bohai fault zone, which is consistent with the active structure distribution.

3. Every greater-than-Ⅷ intensity area is only affected by a single strong earthquake. These areas are usually located in the vicinity of epicenter of earthquakes greater than Ms7 with closed elliptical shape.

4. The high intensity areas of strong earthquakes usually match the range of seismic source zone. It indicates that the seismic source zone of great earthquakes (Ms ≥8.0) can be delineated in terms of intensity Ⅸ zone and the delineation of seismic source zone for earthquakes (Ms7.0-7.9) can be done based on intensity Ⅷ zone.

Introduction

Intensity evaluation results for historical earthquakes can reflect the potential future seismic risk of a region to a certain extent, and reveal the characteristics of seismic structures, such as the direction and scale of earthquake ruptures. Seismic intensity evaluation generally refers to the process of drawing the isoseismal contours of a previous earthquake, based on a seismic intensity scale. An isoseismal contour is a line connecting points with the same degree of damage (or intensity) for the same earthquake. If the seismic intensity results of a region for a particular previous period of time are combined into a map showing the maximum seismic intensities that the region has experienced in the past, the resulting map is called a comprehensive isoseismal map. This type of map can provide important information for the understanding of earthquake spatial distributions, earthquake intensities, geological structures, and seismic influences.

In this study, we used the North China active block area as the researcher region and produced a comprehensive isoseismal map, thus providing a basis for the assessment of seismic hazard and geological structures in North China. The North China active block area is located from approximately 29°–43°N and 105°–124°E (Fig.1), including the municipalities of Beijing, Tianjin, and Shanghai; the provinces of Hebei, Shandong, Shanxi, and Jiangsu; and the partial areas of the provinces of Liaoning, Inner Mongolia, Ningxia, Shaanxi, Gansu, Henan, Anhui, and Zhejiang.

The North China active block area is the tectonic region with the strongest tectonic activity, the highest seismic frequency, and the greatest seismic strength in Eastern China. There are some well-developed faults in the NE-NNE, NW, and nearly EW directions that intersect one another (Zhang et al., 2003; Han et al., 2003). The 1556 Huaxian Earthquake (magnitude 8 1/4) took place in the approximately EW-trending Huashan Front Fault Zone as the southern boundary of the active block area. The 1668 Tancheng Earthquake (magnitude 8 1/2) occurred on the Tanlu Fault in a NNE direction. The Sanhe-Pinggu Earthquake (magnitude 8) of 1679 and the Tangshan Earthquake (magnitude 7.8) of 1976 occurred at the intersections of the NW-trending Zhangjiakou-Bohai Fault Zone with the NNE-trending Xiadian and Tangshan faults, respectively. Moreover, because North China is also the political, economic, and cultural center of China, the potential seismic risk will undoubtedly increase with the continued development of cities and the concentration of population and wealth.

From the perspective of earthquake records, the seismic risk has not decreased with the advancement of science and technology, or with economic development. On the contrary, the risk has actually increased. For example, the 1976 Ms7.8 Tangshan Earthquake almost destroyed the entire city of Tangshan, taking more than 242,000 lives and causing huge economic losses. In particular, since population and wealth are increasingly concentrated as a result of social and economic development, some moderate-strong earthquakes could also wreak great economic losses. For instance, the 1983 Shandong Heze Earthquake (magnitude 5.9) caused an economic loss of more than 500 million yuan, the 1998 Hebei Zhangbei Earthquake (magnitude 6.3) caused an economic loss of more than 400 million yuan, and the 1999 Shanxi Yanggao Earthquake (magnitude 5.6) caused an economic loss of more than 250 million yuan (National Bureau of Statistics of China and the Civil Affairs Bureau of China, 1995).

Thus, earthquakes occur frequently and there is a higher seismic hazard in this area. With the rapid development of the economy, population and wealth growth, and the diversification of new types of buildings, the seismic risk will continue to increase. Therefore, it is necessary to study the intensities of the historical earthquakes to provide the basic information necessary for a more reasonable and effective assessment of seismic hazards as well as the mitigation of earthquake disasters in this area.

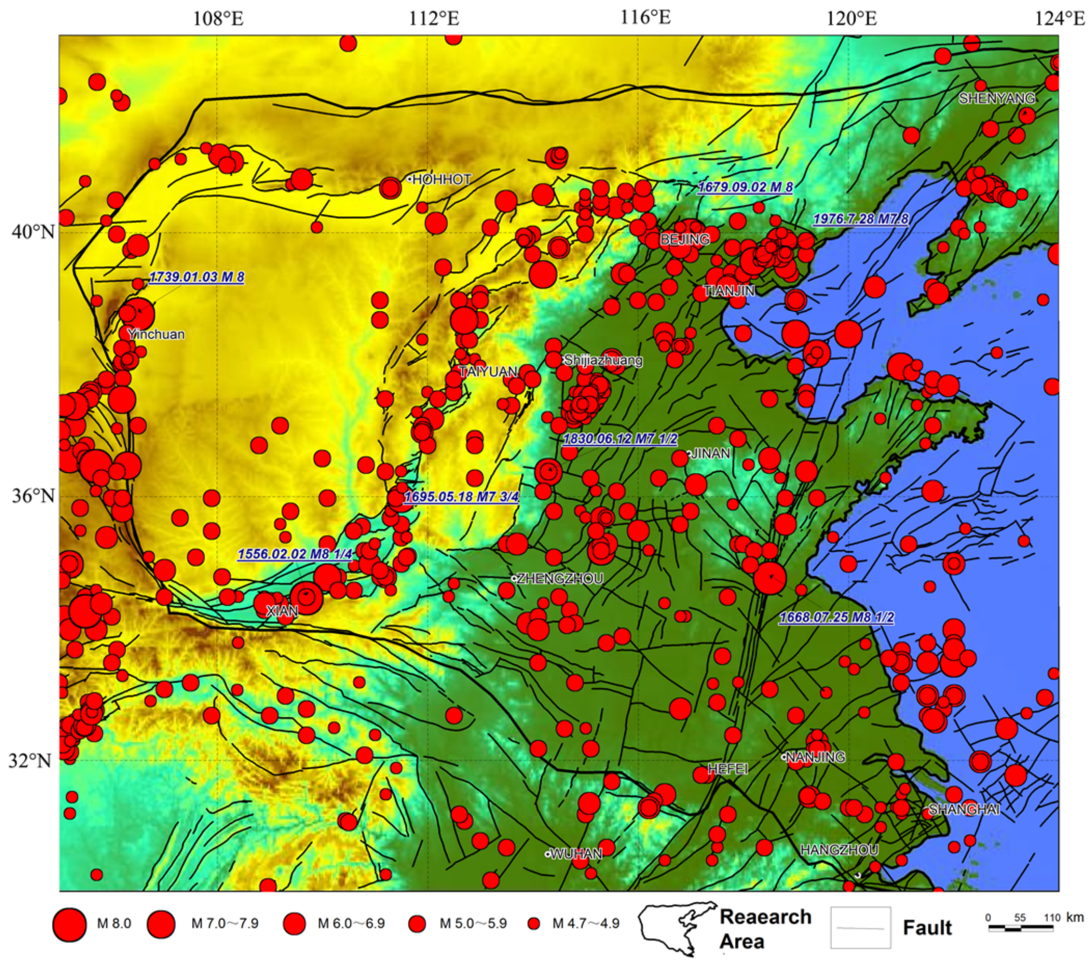


Fig. 1. Distribution of earthquake epicenters in and near the North China active block area

1. Data Sources

Since 1949, an extensive collection and collation of historical earthquake data has been carried out. The first edition of the <Chinese Earthquake Catalogue> was officially published in 1960 (Li et al., 1960). Since then, this catalogue has been supplemented and modified, with revised versions being published in 1971 and 1983. In the 1990s, the <Historical Strong Earthquake Catalogue of China (2300 BC–1911)> (Bureau of Earthquake Damage Protection of the China Earthquake Administration, 1995) and the <Modern Strong Earthquake Catalogue of China (Ms ≥ 4.7, 1912–1990) >were published (Bureau of Earthquake Damage Protection of the China Earthquake Administration, 1999). These two publications are the latest and most comprehensive officially published earthquake catalogues of China.

Through comparative analyses of the recording accuracy and the reliability of the isoseismal maps in each version, in this study we elected to employ the seismic intensity data before 1990 mainly from the <Historical Strong Earthquake Catalogue of China (2300 BC–1911)> and the <Modern Strong Earthquake Catalogue of China (Ms ≥ 4.7, 1912–1990)>. The data for destructive earthquakes occurring since 1990 were taken from the <China Earthquake Annual

Report (1991–2000)> and the <China Digital Seismic Network Observation Report (2001–November 2004)>compiled by the Institute of Geophysics of the China Earthquake Administration, as well as the <China Earthquake Catalogue (December 2004–December 2018)> compiled by the China Earthquake Administration Network Center.

Earthquake intensities are assessed based on a seismic intensity scale. The assessment of different intensities and their corresponding ground motion parameters are listed in Table 1. Buildings are not affected much by low-intensity earthquakes; very high intensities are rare and the safeguards they require exceed what people can realistically afford. Therefore, in the 12-level intensity scale, the most frequently used intensities are VI–X, which are evaluated according to earthquake damage to low-rise buildings. This is precisely the intensity range that is most commonly considered in earthquake engineering. Moreover, data with very low intensities are typically not available and not useful. Therefore, a minimum intensity of V was considered in this study.

Table 1 The intensity scale used in this study is the Chinese seismic intensity scale (2008). According to this scale, intensity is divided into 12 grades, I through XII. Following is an abbreviated description of the 12 levels of the Chinese seismic intensity scale

Intensity	Person feeling	Building damage	Other damage	PGA(m/s^2)
I	Not felt			
Ⅱ	Felt only by one or two persons at rest indoors			
Ⅲ	Felt by a few persons at rest indoors	Windows, doors make slight sound	Suspender jiggles	
Ⅳ	Felt indoors by many, outdoors by few. A few persons awakened	Windows, doors make sound	Suspender wiggles, vessels make sound	
Ⅴ	Felt indoors by nearly everyone, outdoors by many. Many awakened.	Doors, windows, roofs vibrate. A few walls slightly cracked. A few chimneys on the roof may be damaged.	Suspender strongly wiggles. Unstable objects overturn.	0.31 (0.22–0.44)
Ⅵ	Many persons cannot stably stand, a few frightened and escape to outdoor.	[a]A: A few moderately damaged, many slightly damaged or almost well [a]B: One or two moderately damaged, a few slightly damaged, almost well [a]C: One or two slightly damaged, nearly every house well	Furniture and objects move, riverside and soft soil crack, one or two brick chimneys slightly cracked	0.63 (0.45–0.89)
Ⅶ	Nearly everyone frightened and escape tooutdoors. Felt by riders on bikes and driversin cars.	A: A few destroyed or heavily damaged, many moderately or slightly damaged. B: A few moderately damaged, many slightly damaged or well. C: A few moderately or slightly damaged, many well.	Objects fall down, riverside collapses, soft soil heavily cracked, many brick chimneys moderately damaged.	1.25 (0.90–1.77)
Ⅷ	Many persons cannot make a move	A: A few destroyed, many heavily or moderately damaged. B: One or two destroyed, a few heavily damaged, many moderately or slightly damaged.	Dry and hard soil cracks, most brick chimneys heavily damaged.	2.50 (1.78–3.53)

		C: A few heavily or moderately damaged, many slightly damaged.		
Ⅸ	Moving persons tumble.	A: Many heavily damaged or destroyed. B: A few destroyed, many heavily or moderately damaged. C: A few destroyed or heavily damaged, many moderately or slightly damaged.	Dry and hard soil heavily cracked, bedrock cracked, landslides appear, many brick chimneys destroyed.	5.00 (3.54–7.07)
Ⅹ	Riders tumble, unstable persons threw up	A: Nearly every house destroyed. B: Almost destroyed. C: Many destroyed or heavily damaged.	Landslip and earthquake faults appear, arch bridge on bedrock destroyed, nearly every brick chimney destroyed.	10.00 (7.08–14.14)
Ⅺ		A, B, C: Nearly every house destroyed.	Earthquake faults take long rupture, and masses of landslip	
Ⅻ		All destroyed.	Ground, mountains and rivers acutely changed.	

[a]**Buildings are divided into three types: A: Old houses built with wood, soil, stone and brick. B: Unfortified monolayer or multilayer brick house. C: Fortified monolayer or multilayer brick houses according to intensity VII.**

According to Huang et al. (1994), with the exception of Inner Mongolia, the Yellow Sea, and remote areas, the records of earthquakes ≥ Ms4 3/4 occurring in North China after 1484 are complete. Moreover, in the North China area, aside from the oceans and the remote regions of Inner Mongolia, earthquakes with intensities ≥ VI occurring before 1500 and with intensities ≥ V occurring after 1500 were recorded in written form. Therefore, we collected all of the data for earthquakes with Ms> 4 3/4 occurring after 1484, including those whose epicenters were in the active block area, and those producing effective intensities > V for the area. As such, a total of 504 earthquakes of Ms ≥ 4.7 were collected, including 175 events between Ms4.7–4.9, 266 between Ms5.0–5.9, 49 between Ms6.0–6.9, 10 between Ms7.0–7.9, and 4 events of Ms ≥ 8.0 (Fig. 1). Table 2 lists the 14 earthquakes of Ms7.0 or greater.

Table 2 Catalog of strong earthquakes (M>7) in North China active block area

No	Date （Y.M.D）	Location			Mag.* (Ms)	EP.I*
		Lat.*	Lat.*	Lat.*		
1	1501.01.29	34.8°	110.1°	Chaoyang, Shaanxi	7	Ⅸ
2	1556.02.02.	34.5°	109.7°	Huaxian, Shaanxi	8 1/4	Ⅺ
3	1626.06.28.	39.4°	114.2°	Lingqiu, Shanxi	7	Ⅸ
4	1668.07.25.	34.8°	118.5°	Yucheng, Shandong	8 1/2	≥Ⅺ
5	1679.09.02.	40.0°	117.0°	Sanhe-Pinggu	8	Ⅺ
6	1683.11.22.	38.7°	112.7°	Near Yuanping, Shanxi	7	Ⅸ
7	1695.05.18.	36°	111.5°	Linfen, Shanxi	7 3/4	Ⅹ

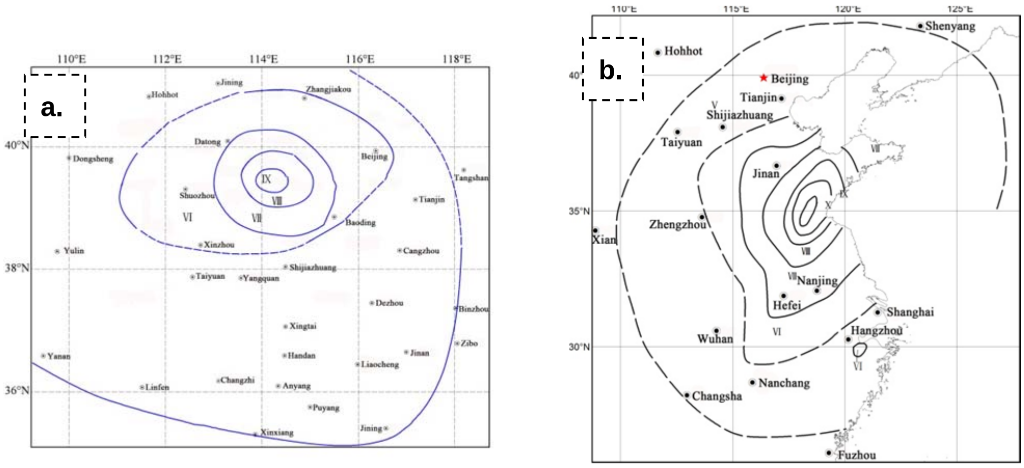
8	1739.01.03.	38.8°	106.5°	Pingluo-Yinchuan, Ningxia	8	X+
9	1830.06.12	36.4°	114.3°	Ci County, Hebei	7 1/2	X
10	1937.8.1	35.2°	115.3°	Heze, Shandong	7.0	IX
11	1966.3.22	37.5°	115.1°	Southeast of Ningjin, Hebei	7.2	X
12	1975.2.4	40.7°	122.7°	Haicheng, Liaoning	7.3	IX+
13	1976.7.28	39.6°	118.2°	Tangshan, Hebei	7.8	XI
14	1976.7.28	39.9°	118.7°	Luan County, Hebei	7.1	IX

2. Creation of the Isoseismal Contour Database

An isoseismal contour database is the basis for the drawing of a comprehensive isoseismal map. In the ArcGIS geographic information system, the main steps for creating an isoseismal contour database are as follows: (1) collect and classify isoseismal maps; (2) determine the descriptions of isoseismal contours and construct a reasonable attribute list; and (3) digitize isoseismal contours and enter various attribute values in the data table.

2.1 Data collecting and pre-processing

The data for the 504 earthquakes that occurred in the North China active block area were digitized on the ArcGIS platform and completely entered into the database. The data with isoseismal contours were digitized in ArcGIS based on the WGS1984 coordinate system. Fig. 2 shows the isoseismal maps of several important earthquakes, including the 1626 Lingqiu Earthquake (magnitude 7), the 1668 Yancheng Earthquake (magnitude 8 1/2), the 1679 Sanhe Earthquake (magnitude 8.0), and the 1976 Tangshan Earthquake (magnitude 7.8).



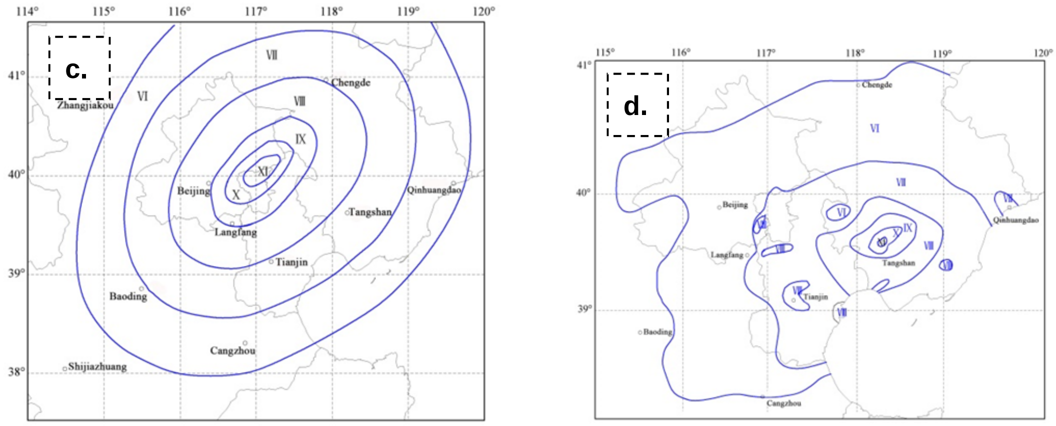


Fig. 2. Isoseismal maps of several important earthquakes
(a) the 1626 Lingqiu 7.0 Earthquake; (b) the 1668 Yucheng 8.5 Earthquake; (c) the 1679 Sanhe 8.0 Earthquake; and (d) the 1976 Tangshan 7.8 Earthquake

For earthquakes without isoseismal maps, without intensity results, or for which only either the epicenter intensity was recorded or a range of the area in which the earthquake was felt was given, the following method was employed: a buffer zone was created centering on the epicenter with a radius of 0.1° (approximately 10 km), depending on the recorded error range. The intensity of the buffer zone is equal to the epicenter intensity. The intensity attenuation relationship equations for East China were then used to calculate the lengths of the long semi-axis and the short semi-axis of an elliptical isoseismal contour for intensity V or larger (Wang et al., 2000):

$$I_a = 5.019 + 1.446M - 4.136\log(R_a + 24) \ \sigma = 0.517$$

$$I_b = 2.240 + 1.446M - 3.070\log(R_b + 9) \ \sigma = 0.517,$$

where I is the seismic intensity, M is the magnitude, and Ra and Rb are the lengths (in units of km) of the long semi-axis and the short semi-axis, respectively, of an elliptical isoseismal contour with intensity I. σ is the standard deviation.

Assuming that the area of an isoseismal ellipse is equal to that of a circle (Gao, 2000), the radius of the circle is called the equivalent circle radius. In the GIS system, the intensity map of each earthquake was drawn using the above equivalent circle radius technique (Fig. 3).

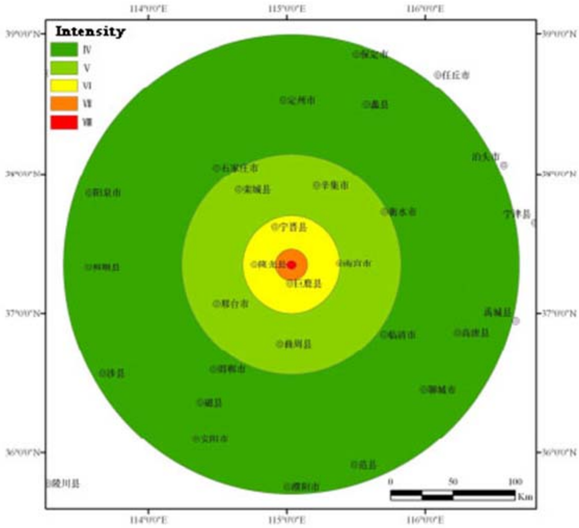


Fig. 3. Isoseismal map of the 1966 Hebei Julubei Ms6.0 Earthquake drawn using the intensity attenuation relationship
The red central area is the epicenter buffer. Intensities in the buffer are all equal to the epicenter intensity.

2.2 Isoseismal contour digitization

The first step in digitizing isoseismal contours is registering an isoseismal map. The key issues involved are map projection and selecting registration control points.

Most isoseismal maps are created based on topographic maps. China's 1:1,000,000 topographic maps, which prior to 1978 used the international one-millionth projection (also known as the Modified Polyconic Projection), now use Lambert's Conic Conformal Projection. Given the small difference from Lambert's Conic Conformal Projection, the Modified Polyconic Projection is ensured to have sufficient accuracy when registering isoseismal lines. China's topographic maps with 1:500,000 and larger scales employ the Unified Gauss-Krüger Projection. In order to ensure both accuracy and reasonable map splicing, isoseismal contours are reviewed prior to registration. If the scale is less than 1:500,000, Lambert's Conic Conformal Projection is utilized. Otherwise, the Gauss-Krüger Projection is employed.

Most isoseismal maps are highly inaccurate and not standardized. In addition, the latitude and longitude may not be clearly marked on the map boundaries. Therefore, when control points are registered, it is usually done by matching the location names. The method is as follows: based on the 1:500,000 geographical name database from the basic geographic information system of China, 4–5 counties (cities) or residential locations are uniformly selected as the control points for registering isoseismal contours. Most results for isoseismal contour registration indicate that the registration accuracy can generally satisfy the requirements.

After the isoseismal maps have been registered, isoseismal contours can then be digitized in the isoseismal line layer, and attribute values can be entered in the corresponding data table.

3. Drawing of the comprehensive isoseismal map of North China

3.1 Method for drawing a comprehensive isoseismal map

After the layers of isoseismal contours and equal-intensity zones have been created for each isoseismal map, the isoseismal contour database is established, which can then be used to create a comprehensive isoseismal map. At this point, the layer to be used is that of the equal-intensity zone. A comprehensive isoseismal map can be created by using the topological overlay technique for all the equal-intensity zone layers. The details are as follows.

First, a new project file is created. In the project file, a new blank map layer is created with a suitable geographic coordinate system and an attribute list consistent with the equal-intensity zone layer. Moreover, all of the equal-intensity zone layers are loaded into the project file. All of the equal-intensity zones are then selected and copied into the blank map layer in Copy mode.

In this map layer, the equal-intensity zones are selected and merged. The intersection of the "selected zones" and all other zones are then cut off, e.g., the maximum intensity area (above intensity X) is selected, and then the intersection of the other intensity areas and the maximum intensity area are cut off. From the maximum intensity zone to the minimum intensity zone, cutting is performed in turn until all the intensity zones no longer have intersecting parts, thus creating comprehensive isoseismal contours.

3.2 Comprehensive isoseismal map of North China

Fig. 4 is the comprehensive isoseismal map of the North China active block area drawn in this study. From this map, we can make the following observations.

1. Since 1484, 80% of the North China active block area—the only exceptions being Erdos City, middle and eastern Inner Mongolia, and the middle part of the Huaihe River Basin—have experienced earthquake intensities greater than VI. The areas affected by VI, VII, VIII, IX, X, and XI earthquakes are 388,200; 428,300; 170,100; 75,290; 30,100; and 6,511 km2, respectively. The maximum intensity was XII, at the epicenter of the Shandong-Yucheng Earthquake (magnitude 8.5) in 1668, affecting an area of 1,276 square kilometers.

2. Intensities greater than VII were widely distributed in obvious bands, mainly along the Huashan front fault, the Fenwei fault depression zone, the Tanlu fault zone, and the Zhangjiakou-Bohai fault zone, a pattern that is consistent with the active tectonic structure distribution of the study area.

3. Every area with an intensity greater than VIII was caused by a single earthquake. These areas were usually located in the vicinity of the epicenters of earthquakes greater than Ms7.0 in a closed elliptical shape. All major axes of elliptical areas were basically located along the strikes of active structures. However, the proportion of major axis to minor axis was small. This is due to the fact that most earthquakes greater than Ms7.0 in North China have occurred at the intersection of active structures with NE and NW strikes. The surface in this area is covered by thick sediment and the surface faults are not as well-developed as those in West China.

4. Analysis revealed that the high-intensity areas of strong earthquakes usually matched the range of the seismic source zones. The seismic source zones of earthquakes with $Ms \geq 8.0$ and Ms7.0–7.9 could be defined using the zones of intensities IX and VIII, respectively.

5. Statistics showed that the distribution of small and moderate earthquakes did not exhibit an obvious correlation with high intensity (greater than VII) zones.

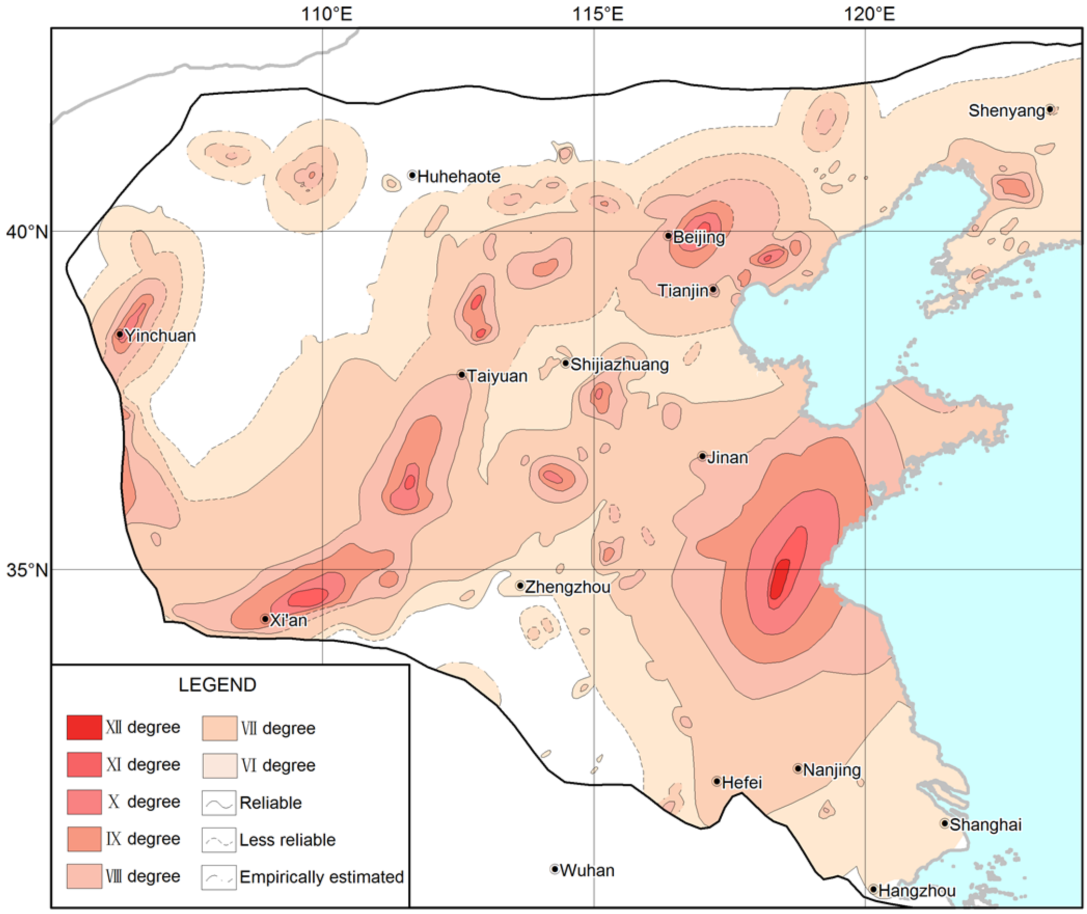


Fig. 4. Maximum intensity map of the North China active block area (after 1484)

4. Conclusions

Compared with the previous comprehensive isoseismal maps of China, the comprehensive isoseismal map created in this study for the North China active block area has the following characteristics.

(1) This study employed several historical earthquake catalogues and the seismic data for destructive earthquakes from 1484–2010. Following an integrity check, a comparison of record accuracy, and the deletion of aftershock data, a total of 504 historical earthquakes were identified for this investigation. These included 265 ancient historical earthquakes (1484–1911) and 239 modern earthquakes (1912–2010). Fourteen earthquakes had magnitudes ≥ 7. Eight events had epicenter intensities of X or larger. A total of 247 isoseismal maps were utilized. A seismic intensity database was created using the GIS platform.

(2) GIS was employed to manage the isoseismal contour data and draw isoseismal maps. The use of GIS has greatly improved work efficiency and reduced error rates. Meanwhile, the

establishment of the isoseismal contour database also provides a convenient resource for future updates.

(3) Isoseismal maps for earthquakes of magnitude 7 or higher were updated according to the Historical Strong Earthquake Catalogue of China (from 2300 BC–1911).

The comprehensive isoseismal map (or the maximum intensity map) for earthquakes occurring since 1484 in the North China active block area illustrates the maximum intensity distribution of this region using the latest data. The basic distribution patterns of the high-intensity area along the active block boundaries and the internal active fault zones display a close relationship to the geological structure. The historical intensity and geological structure information exhibited in this map are of significance for ground motion parameter zoning, land use planning, and decision-making in both earthquake prevention and disaster reduction.

References

China Earthquake Administration China Earthquake Zoning Map Editorial Board, 1991. China Comprehensive Isoseismal Map (Manual Included). Beijing: Seismological Press.

Bureau of Earthquake Damage Protection of the China Earthquake Administration, 1995. Historical Strong Earthquake Catalogue of China (2300 BC–1911). Beijing: Seismological Press.

Qu CY, Ye H, 1999. Drawing comprehensive isoseismal lines using the topological overlay principle of GIS. Seismology and Geology, 21(2): 156-158.

Sha HJ, Lv YJ, Zhao JT et al., 2008. A Simple Method of Drawing Comprehensive Isoseismal Map with ArcView Tool. Technology for Earthquake Disaster PreventioN, 3(1): 95-99.

China Earthquake Administration, 2001. Seismic ground motion parameter zonation map of China. Beijing: Standards Press of China.

Bureau of Earthquake Damage Protection of the China Earthquake Administration, 1999. Modern Strong Earthquake Catalogue of China (1912–1990). Beijing: China Science and technology Press.

Qu GS, Li YG, Huang XR, Xu JD translate, 2000. ArcView GIS. Beijing: Seismological Press, 1-280.

National Bureau of Statistics, Civil Affairs Bureau, 1995. Report of the damage Gaused by disaster in China. Beijing: China Statistics Press

Huang WQ, Li WX, Cao XF, 1994. Integrity of earthquake data in mainland China, I—Taking North China as an example. Acta Seismologica Sinica, 16 (3): 273-280

Xie YS, Cai MB, Wang HA, et al. 1983-1987. China Earthquake Historical Data Compilation (I–V). Beijing: China Science and technology Press

Zhang P Z, Deng Q D, Zhang G M, Ma J, Gan W J, Min W, Mao F Y, Wang Q. Strong seismic activity and active tetonic blocks in mainland China [J]. Scientia Sinica (Terrae), 2003(S1):12-20

Han Z J, Xu J, Ran Y K, Chen L C, Yang X P. Active block and strong seismic activity in North China [J]. Scientia Sinica (Terrae), 2003(S1):108-118.