Analysis of the Regional Characteristics of Seismic Intensity Attenuation Relationships in Sichuan

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Abstract. Using the intensity data of historical destructive earthquakes in Sichuan such as the 2008 Wenchuan earthquake, the Lushan earthquake, and the Jiuzhaigou earthquake, according to the statistical relationship of each seismic center intensity, magnitude, and radius of each intensity circle, this paper established attenuation relationships of the seismic intensity along the long axis, the short axis, and the average axis. Combining the regional seismotectonic characteristics and previous research results, the seismic intensity attenuation relationships have regional characteristics in the high mountains of northwest Sichuan, the Sichuan Basin and surrounding areas, the Southern Sichuan to the Sichuan–Yunnan junction, and the surrounding areas of the Xianshuihe fault. The result of this paper can be used in the practice of rapid assessment of the impact and loss of earthquake disasters.

Keywords: Seismic intensity, Attenuation relationship, Regional characteristics, Sichuan
1. Introduction

The regional characteristics of the seismic intensity attenuation relationship are strong [1], so they play a fundamental role in the rapid assessment of earthquake disaster losses and the seismic safety evaluation of engineering sites to study the attenuation relationship of seismic intensity suitable for a region. In the case of the Sichuan region, many scholars have provided different research results [2-9]. These achievements have their scope of application and limitations. They all study the intensity attenuation characteristics of large-scale regions, which submerge the regional characteristics of seismic activity and seismic damage distribution in various regions of Sichuan, and cannot meet the current demand for accurate and rapid earthquake assessment. The topography of Sichuan Province is complex and diverse. It spans several geomorphic units, such as the Qinghai-Tibet Plateau, Yunnan Guizhou Plateau, Hengduan Mountains, Qinba Mountains, and Sichuan Basin. The terrain is high in the west and low in the east, sloping from northwest to southeast. The highest point is Gongga Mountain, the main peak of the Hengduan Mountains in the west, with an elevation of 7556 m. The lowest point is on the banks of the Yangtze River in Hejiang County, Luzhou City, at an altitude of ~220 m. Topography has an effect on the attenuation of seismic intensity based on the characteristics of the Sichuan area and with the existing research; this paper explores the spatial distribution characteristics of the seismic intensity attenuation relationship in Sichuan.

2. Data and method

The data used in this paper are mainly from two sources: (1) “The Complete Record of Sichuan Earthquakes” [10] and (2) the reports prepared by the Sichuan Earthquake Agency during earthquake disaster loss assessment work. Considering the consistency of the data, it only collects and organizes the seismic data with seismic intensity circles after 1900. According to the time sequence of earthquakes, there were a total of 62 earthquakes with Ms ≥ 5.0, from the Luhuo Ms 7.3 earthquake that happened on March 24, 1923 to the Shiqu Ms 5.6 earthquake that happened on April 1, 2020. The earthquake case data are shown in Table 1.

Table 1. The earthquake case data for intensity attenuation in the Sichuan region.

| No. | Time     | Location | Longitude | Latitude | Ms  |
|-----|----------|----------|-----------|----------|-----|
| 1   | 19230324 | Luhuo    | 100.8     | 31.3     | 7.3 |
| 2   | 19330825 | Maoxian  | 103.70    | 30.00    | 7.5 |
| 3   | 19351218 | Mabian   | 103.2     | 28.7     | 6   |
| 4   | 19360427 | Mabian   | 30.9      | 103.6    | 6.7 |
| 5   | 19480525 | Litang   | 29.5      | 100.5    | 7.3 |
| 6   | 19520930 | Mianning | 29.6      | 102.5    | 6.8 |
| 7   | 19541024 | Zigong   | 29.4      | 104.8    | 5   |
| 8   | 19550414 | Kangding | 30        | 101.8    | 7.5 |
| 9   | 19550923 | Huili    | 26.2      | 101.9    | 6.9 |
| 10  | 19601109 | Songpan  | 103.42    | 32.42    | 6.8 |
| 11  | 19670124 | Panzhihua| 30.2      | 104.1    | 5.5 |
| 12  | 19700224 | Dayi     | 30.6      | 103.3    | 6.2 |
| 13  | 19700731 | Pingshan | 28.6      | 103.7    | 5.4 |
| No. | Date       | Location          | Lat.  | Long.  | Depth |
|-----|------------|-------------------|-------|--------|-------|
| 14  | 19720927   | Kangding          | 30.4  | 101.7  | 5.8   |
| 15  | 19730206   | Luhuo             | 100.4 | 31.5   | 7.6   |
| 16  | 19730811   | Songpan           | 104   | 32.53  | 6.5   |
| 17  | 19740923   | Ruergai           | 33.8  | 102.6  | 5.6   |
| 18  | 19760816   | Songpan-Pingwu    | 104.06| 32.41  | 7.2   |
| 19  | 19760823   | Songpan-Pingwu    | 104.3 | 32.5   | 7.2   |
| 20  | 19761107   | Yanyuan-Ninglang  | 101.03| 27.32  | 6.7   |
| 21  | 19761213   | Yanyuan-Ninglang  | 101.03| 27.32  | 6.7   |
| 22  | 19820616   | Ganzi             | 99.51 | 31.5   | 6     |
| 23  | 19860807   | Litang            | 100.48| 29.17  | 5.6   |
| 24  | 19860812   | Yanyuan           | 101.2 | 27.19  | 5.2   |
| 25  | 19880415   | Huidong-Luquan    | 102.45| 36.18  | 5.2   |
| 26  | 19880602   | Daofu             | 101.28| 30.35  | 5     |
| 27  | 19890301   | Xiaojin           | 102.26| 31.3   | 5     |
| 28  | 19890416   | Batang            | 99.15 | 39.58  | 6.7   |
| 29  | 19890609   | Shimian           | 102.13| 29.16  | 5.2   |
| 30  | 19890922   | Xiaojin           | 102.22| 31.37  | 6.6   |
| 31  | 19900804   | Hongya-Jinkouhe   | 103.1 | 29.5   | 5     |
| 32  | 19930524   | Dege              | 98.48 | 31.47  | 5     |
| 33  | 19930807   | Muchuan           | 103.36| 29.01  | 5     |
| 34  | 19941230   | Muchuan           | 103.39| 29.01  | 5.7   |
| 35  | 19950426   | Muchuan           | 103.39| 28.59  | 5.1   |
| 36  | 19960228   | Yibin             | 104.38| 29.02  | 5.4   |
| 37  | 19961221   | Baiyu-Batang      | 99.6  | 30.7   | 5.5   |
| 38  | 19970813   | Rongchang         | 105.33| 29.27  | 5.2   |
| 39  | 19990914   | Mianzhu           | 104.05| 31.36  | 5     |
| 40  | 19991130   | Mianzhu           | 104.2 | 31.26  | 5     |
| 41  | 20010223   | Yajiang           | 101.06| 29.24  | 6     |
| 42  | 20020808   | Xinlong           | 100   | 30.9   | 5.3   |
| 43  | 20030821   | Yanyuan           | 101.3 | 27.4   | 5     |
| 44  | 20081130   | Renhe-Huili       | 101.9 | 26.2   | 6.1   |
| 45  | 20080512   | Wenchuan          | 103.42| 31.01  | 8     |
| 46  | 20130420   | Lushan            | 103   | 30.3   | 7     |
| 47  | 20130831   | Derong            | 99.4  | 28.2   | 5.9   |
| 48  | 20141001   | Yuxi              | 102.8 | 28.4   | 5     |
| 49  | 20141125   | Kangding          | 101.7 | 30.3   | 6.3   |
| 50  | 20150114   | Jinkouhe          | 103.2 | 29.3   | 5     |
| 51  | 24511225   | Litang            | 99.61 | 30.1   | 5.1   |
| 52  | 20170808   | Jiuzhaigou        | 103.82| 33.2   | 7     |
| 53  | 20170930   | Qingchuan         | 105   | 32.27  | 5.4   |
| 54  | 20180912   | Ningqiang         | 105.69| 32.75  | 5.3   |
| 55  | 20181031   | Xichang           | 102.08| 27.7   | 5.1   |
| 56  | 20181216   | Xingwen           | 104.95| 28.24  | 5.7   |
| 57  | 20190103   | Gongxian          | 104.86| 28.2   | 5.3   |
| 58  | 20190617   | Changning         | 104.9 | 28.34  | 6     |
| 59  | 20190908   | Weiyuan           | 104.79| 29.55  | 5.4   |
| 60  | 20191218   | Zizhong           | 104.82| 29.59  | 5.2   |
| 61  | 20200203   | Qingbaijiang      | 104.46| 30.74  | 5.1   |
| 62  | 20200401   | Shiqu             | 98.92 | 33.04  | 5.6   |
3. Results and analysis

3.1 Regional characteristic analysis of seismic intensity attenuation relationship in Sichuan

In mountainous areas with large undulations, especially when the epicenter was located in the valley zone (a large strike-slip fault and block boundary fault), the seismic intensity circle appears as a narrow strip band distribution along the direction of the valley due to the influence of the propagation direction of the earthquake rupture, shown in Figures 1 and 2.

![Figure 1. Intensity distribution map of the Luhuo Ms 7.3 earthquake in 1923.](image)

![Figure 2. Intensity distribution map of the Luhuo Ms 7.6 earthquake in 1973.](image)

According to the seismic intensity map of the Songpan-Pingwu Ms 7.2 earthquake in 1976, the Wenchuan Ms 8.0 earthquake in 2008, and the Lushan Ms 7.0 earthquake in 2013, which are distributed in the transition zone between mountain and plain, we can see that the intensity attenuation along the low altitude is slower than along the high altitude, so the low altitude area affected by the earthquake is larger than the high altitude area. The ratio of the radius of the intensity circle along the high altitude and low altitude of several earthquakes is shown in Table 2.
Table 2. The ratio of the radius of the seismic intensity circle along the high and low altitude in the transitional area between mountains and plains in Sichuan.

| Earthquake name                  | The ratio of the radius of 11 degree | The ratio of the radius of 10 degree | The ratio of the radius of 9 degree | The ratio of the radius of 8 degree | The ratio of the radius of 7 degree | The ratio of the radius of 6 degree |
|----------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Songpan-Pingwu Ms7.2 earthquake  | null                                 | null                                 | 0.4706                               | 0.8669                               | 0.8000                               | 0.6200                               |
| Lushan Ms7.0 earthquake          | null                                 | null                                 | 0.8772                               | 0.6500                               | 0.6612                               | 0.6849                               |
| Wenchuan MS8.0 earthquake        | 0.7225                               | 0.6636                               | 1.1765                               | 1.0968                               | 0.8000                               | 0.8000                               |

3.2 Regional division

Affected by the seismotectonic environment, the seismicity and earthquake damage in continental China have obvious regional characteristics [8]. According to the seismotectonic environment, the distribution characteristics of earthquake damage and the influence of topography, the active faults in the high mountains or plateau areas of northwest Sichuan are all Holocene strike-slip faults. The attenuation in the short axial direction is rapid, and it is distributed in a long and narrow ellipse, especially in the Xianshuihe fault zone. Therefore, the Xianshuihe fault zone is considered as one zone, and the rest of the high mountains or plateau areas of northwest Sichuan are the other zone. The Chengdu Plain and Northeastern Sichuan Basin area are mainly folded associated faults, which belong to inactive faults, and the seismic intensity attenuation is uniform in the long- and short-axis directions. The active faults in the Southern Sichuan and Sichuan–Yunnan border regions are mainly subfaults, and the seismic intensity presents a regular ellipse. Therefore, this paper divides Sichuan into four regions: the Xianshuihe fault area, the Northwest Sichuan Plateau, the Chengdu Plain and Northeastern Sichuan Basin area, and the Southern Sichuan and Sichuan–Yunnan border regions (Figure 3).
3.2.1 Xianshuihe fault area. The Xianshuihe fault zone strikes from northwest to southeast, starting from Ganzi, Sichuan in the north, passing through Luhuo, Daofu, Qianning, and Kangding to the south, and is connected to the Anninghe fault zone and Xiaojiang fault zone in the south, and is as long as 400 km. It is a large left-handed strike-slip fault zone and seismic zone that is developing along the Xianshui River Valley. The attenuation speed of the earthquake intensity in the short-axis direction is much faster than that in the long-axis direction especially for the intensity circle of above 8 degree and the long axis is at least four times more than the short axis. Historical earthquake data are shown in Table 3.

| Earthquake name | The ratio of the radius of 6 degree | The ratio of the radius of 7 degree | The ratio of the radius of 8 degree | The ratio of the radius of 9 degree | The ratio of the radius of 10 degree |
|-----------------|-----------------------------------|-----------------------------------|-------------------------------|-----------------------------------|-----------------------------|
| LuHuo Ms7.3 earthquake | 2.10 | 2.60 | 4.08 | 6.83 | null |
| LuHuo Ms7.6 earthquake | 1.67 | 2.70 | 5.65 | 6.80 | 10.25 |
| Ganzi Ms5.8 earthquake | 3.38 | 5.67 | null | null | null |

3.2.2 The Northwest Sichuan Plateau. This area includes the Longmenshan seismic zone, East Kunlun fault, Longriba fault, Huya fault, Minjiang fault, Pingwu-Qingchuan fault,
Fubianhe fault, Yushu-Ganzi fault southern section, Yunongxi fault, Litang fault zone, and the middle section of the Jinshajiang fault zone and surrounding areas, except for the Xianshuihe fault zone in the mountain (original) area of northwest Sichuan. It is obvious that earthquakes in this area are influenced by fault activities. The modes of seismogenic fault activities are the main strike–slip and reverse strike–slip [5]. However, the attenuation rate in the short-axis direction of the earthquake-affected field in this area is slower than the Xianshuihe fault zone area.

3.2.3 The Chengdu Plain and Northeastern Sichuan Basin. This area is located to the south of the Longmenshan fault zone and to the east of the Daliangshan fault zone. It is in the transition zone from the Qinghai-Tibet Plateau to South China. So, the terrain is relatively flat, the crustal structure is relatively uniform, and the fault scale is small and weak. The nature of the faults is mainly reverse faults, and seismic activities are affected by faults or folds that coexist with faults. The frequency and strength of seismic activity are relatively low. Most of the earthquakes in this region are mainly moderate magnitude 5 or so except for the Mabian and Leibo areas that may reach magnitude 6 to 7. The distribution of the earthquake-affected field in this area presents a certain directional ellipse, which is closer to a circle.

3.2.4 The Southern Sichuan–Northern Yunnan border area. This area mainly includes the Zemuhe Fault, Anninghe Fault, Daliangshan Fault, Yanyuan Arc Tectonic Belt, Xigeda Fault, North Section of the Xiaojiang Fault, and surrounding areas. Many strong earthquakes with Ms≥ 7 occurred in this area. The frequency and intensity of seismicity are high. The direction of earthquake rupture is close to the north–south direction, and the intensity circle is larger than The other three regions.

4. Conclusion

After the analysis and calculation, combined with the geological structural conditions of the Sichuan area and historical seismic statistics, the Sichuan area is divided into the Xianshuihe fault area, the Northwest Sichuan Plateau, the Chengdu Plain and Northeastern Sichuan Basin, and the Southern Sichuan and Sichuan–Yunnan border regions. Through the collected historical seismic data, it can be seen that the regional characteristics of the seismic impact field of each subarea are obvious. Among them, the Xianshuihe fault zone is where the seismic impact field attenuates the fastest, followed by the Northwest Sichuan Plateau, and the third is the Chengdu Plain and Northeastern Sichuan Basin. The slowest is the Southern Sichuan–Northern Yunnan border area. Analysis of regional characteristics of the seismic intensity attenuation relationship in Sichuan is important for the rapid assessment of the earthquake influence field and the delineation of the seismic intensity map.
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