Research Article

G-R Curves Based on Weibull Distribution

Yubo Wang,1 Jie Yu,2 Gang Shen,2 and Tiebin Wang2

1School of Geophysics and Geomatics, China University of Geosciences, Wuhan 430074, China
2School of Mechanical and Resource Engineering, Wuzhou University, Guangxi 543002, China

Correspondence should be addressed to Jie Yu; yj@gxuwz.edu.cn and Gang Shen; gang.shen@utas.edu.au

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China Earthquake time intervals have been calculated and passed the hypothesis test based on Weibull distribution. Comparative analyses have been carried out with the China Earthquake Catalogue according to different time intervals and different zones. From the results, we can see that the shape parameters are enlarged with the year’s extrapolation. b value curves and Amira images of the global plate subduction zones have been drawn, and the parameters of Weibull Distribution have been calculated. The relationship diagrams of b values and the parameters of Weibull Distribution of the whole subduction zones have been drawn.

1. Introduction

Weibull distribution possesses rich predictions contents which can be applied in the analysis of the reliability and risks of the systems [1–4]. Weibull distribution contains three parameters such as shape parameter, scale parameter, and position parameter. Exponential distribution and normal distribution can be looked as the special cases of Weibull distribution which is applicable of all types of tests and is used widely in all areas [5–9].

We analyzed the interval between earthquakes in Taiwan (From Jan. 1st 1973 to Dec. 31st 2010) and drew the scatter diagram of density function and distribution function. We think that the distribution type is Weibull distribution. The parameters of Weibull distribution are estimated, and the linear correlation test is carried out to obtain the regression equation [10, 11]. Finally, the hypothesis test is carried out. The distribution of earthquake interval time conforms to the hypothetical Weibull distribution, while the exponential distribution does not pass the hypothesis test. The Weibull distribution parameters in Taiwan are obtained as follows: shape parameter: \( \hat{k} = 1.011 \) and scale parameter: \( \hat{b} = 115.55 \).

2. Earthquake Data Based on Weibull Distribution

We analyze the earthquake data of China from USGS, and we draw the conclusion that the earthquake time intervals obey Weibull distribution [12, 13]. The time of the catalog is from Jan. 1, 1973 to Dec. 31, 2015, and the earthquake magnitude is above 4.0 and the depth of focus is from 0 to 70 km.

We group the earthquake catalog of China according to the areas and study the rules followed of the different parts. These are Taiwan areas, Kunlun-Qilian Mountains-Qinling areas, Tibet and Xinjiang areas, Sichuan and Yunnan areas, Erdos-Qilian Mountains-Qinling areas, North of China, and Northeast of China. Then, we analyze the laws followed by the whole earthquake catalog.

We group the earthquakes that occurred in the areas according to intervals of each year and get forty-three groups. The earthquake intervals of these areas all accord to Weibull distribution and pass through hypothesis tests. We calculate the parameters of Weibull distribution of other areas which are given as below:

From Table 1, we can see that the estimated parameters \( \hat{b} \) and \( \hat{k} \) of different areas are different and the correlation
parameters are also different. There are always some states showing a single peak in the curve of density function, and the shape parameter \( \hat{k} \) changes around 1.0.

From the above analysis, we can think that the earthquake intervals obey Weibull distribution \([14, 15]\). We can discuss the changes of \( b \) and its laws when \( \hat{k} \) is about 1.0.

We analyze the earthquake data in China earthquake catalog from Jan. 1, 1973 to Dec. 31, 2010 with the magnitude lower limit of 4.0. The parameters and \( b \) values are given in Table 2. We contrast the results with the data from Jan. 1, 1973 to Dec. 31, 2015.

From Table 2, we can see that \( b \) values from 1973 to 2010 are lower than those from 1973 to 2015 and the shape parameters \( \hat{k} \) correspondingly deduce.

Shape parameters can be used to describe the possibility of earthquake occurrence over time. When the shape parameter is less than 1, it indicates that the possibility of earthquake decreases with time. When the shape parameter is equal to or approximate to 1, it means that the possibility of earthquake will not change with time, and the occurrence of earthquake is accidental.

### 3. B Value Analysis Based on Weibull Distribution of the Global Plate Subduction Zone

According to the seismic catalog which comes from USGS during 1st Jan. 1973 and 31st December 2015. We get earthquakes above level 4.0, and we draw the temporal clustering of global seismic image. \( x \)-axis shows the subduction zones, and \( y \)-axis shows the time. Different earthquake levels show with different color balls. Blue balls show the levels from 4.0 to 4.9. Green balls show the levels from 5.0 to 5.9. Pink balls show the levels from 6.0 to 6.9. Yellow balls show the levels from 6.0 to 6.9. Red balls show the levels above 8.0.

From Figure 1, we can see that the global subduction zones consisting of several main seismic clustering and the central pacific plates cluster intensive earthquakes and the central pacific zones often have earthquake and erupt frequently \([16, 17]\). There are a series of trenches, islands, and volcanoes on the central pacific plates with violent plate movements. The Alpine-Himalayan belt is clustered earthquakes where are mainly east-west huge mountains across the central and southern Eurasia and northern Africa.

The earthquakes are also active in mid-Atlantic ridge extending south-north of the Pacific ocean which lies in the middle of the ocean basin and extends to the series of mainland shore between flat abyssal plains. Figure 2 is the 3D image of the global catalog with the depth. From the depth, we can see that the earthquakes cluster intensively around the east ridge and the west ridge of the Pacific plates and distribute widely in the depth.

The seismic catalog of the whole Pacific seismic belt, Eurasian seismic zone, and Ridge earthquake belt shows the obvious earthquake cluster properties in terms of time and space. Therefore, we can get the main activity properties of the main plate belts of the whole global from the

| The areas                      | \( \hat{\rho} \) | \( \rho_a \) | \( b \) | The estimated parameters (1973-2015) | \( t = 516 \) |
|-------------------------------|-------------|-------------|-----|-------------------------------------|-----------|
| Taiwan areas                  | 0.9915      | 0.2705      | 0.97| \( \hat{k} = 1.021 \)               | \( \hat{b} = 126.43 \) |
| Kunlun-Qilianshan-Qinling areas | 0.9896     | 0.2705      | 0.90| \( \hat{k} = 1.169 \)               | \( \hat{b} = 128.26 \) |
| Tibet and Xinjiang areas      | 0.9872      | 0.2705      | 0.98| \( \hat{k} = 1.152 \)               | \( \hat{b} = 135.71 \) |
| Tianshan areas                | 0.9722      | 0.2705      | 0.97| \( \hat{k} = 1.099 \)               | \( \hat{b} = 132.87 \) |
| Chuanbian areas               | 0.9811      | 0.2705      | 0.92| \( \hat{k} = 1.206 \)               | \( \hat{b} = 129.21 \) |
| Erdos-Qilianshan-Qinling areas | 0.9921     | 0.2705      | 1.07| \( \hat{k} = 1.079 \)               | \( \hat{b} = 117.33 \) |
| North of China                | 0.9601      | 0.2705      | 0.65| \( \hat{k} = 1.301 \)               | \( \hat{b} = 169.65 \) |
| The total of the eight areas   | 0.9822      | 0.2705      | 0.94| \( \hat{k} = 1.152 \)               | \( \hat{b} = 137.68 \) |
| Mainland and Taiwan areas     | 0.9801      | 0.2705      | 0.98| \( \hat{k} = 1.011 \)               | \( \hat{b} = 105.97 \) |
Weibull parameters of the global catalog are given as below: $\hat{k} = 1.110$, $\hat{b} = 128.59$, $t = 463$ m.

The shape parameter is greater than 1, and we can think that the occurrence of earthquake is accidental.

We divide the global plate subduction zone into 338 parts (as shown in Figure 5). For the parts with no records, we do not analyze. For some seismic zones, we cannot draw $b$ value curves because the earthquake levels below 5.0. The data are also from USGS during 1st Jan. 1973 and 31st December 2015.

We select representative subduction zones and draw $b$ value curves and 3D images and calculate Weibull parameters [18–20]. We analyze the physical meanings of the fault zones.

Subduction 10 (longitude: 142-180, latitude: 60-51): $b$ value curve and 3D image are given as Figures 6 and 7.

We get Weibull parameters of subduction 10: $\hat{k} = 1.05$, $\hat{b} = 114.31$.

Subduction 177 (longitude: 118.93-135.18, latitude: 12.52-3.05): $b$ value curve and 3D image are given as Figures 8 and 9.

We get Weibull parameters of subduction 177: $\hat{k} = 1.03$, $\hat{b} = 105.09$.

From Figure 6–9, the shape parameters are all close to 1.0, and we can think that the occurrence of earthquake is accidental.

Table 2: The contrast analysis of China earthquake catalog.

| The areas                  | The estimated parameters (1973–2015) | $b$ (the magnitude lower limit of 4.0) | The estimated parameters (1973–2010) | $b$ (the magnitude lower limit of 5.0) |
|---------------------------|-------------------------------------|--------------------------------------|-------------------------------------|--------------------------------------|
|                           | $\hat{k}$ = 1.021                    | $b = 0.97$                           | $\hat{k}$ = 1.011                    | $b = 0.99$                           |
|                           | $\hat{b} = 126.43$                  |                                       | $\hat{b} = 115.55$                  |                                       |
| Kunlun-Qian Shan–Qinling areas | $\hat{k}$ = 1.169                    | $b = 0.90$                           | $\hat{k}$ = 1.233                    | $b = 0.87$                           |
|                           | $\hat{b} = 128.26$                  |                                       | $\hat{b} = 136.65$                  |                                       |
| Tibet and Xinjiang areas  | $\hat{k}$ = 1.152                    | $b = 0.98$                           | $\hat{k}$ = 1.172                    | $b = 0.99$                           |
|                           | $\hat{b} = 135.71$                  |                                       | $\hat{b} = 140.63$                  |                                       |
| Tianshan areas            | $\hat{k}$ = 1.099                    | $b = 0.97$                           | $\hat{k}$ = 1.077                    | $b = 0.98$                           |
|                           | $\hat{b} = 132.87$                  |                                       | $\hat{b} = 135.52$                  |                                       |
| Chuan dian areas          | $\hat{k}$ = 1.206                    | $b = 0.92$                           | $\hat{k}$ = 1.125                    | $b = 0.90$                           |
|                           | $\hat{b} = 129.21$                  |                                       | $\hat{b} = 130.19$                  |                                       |
| Erdos-Qian Shan–Qinling areas | $\hat{k}$ = 1.079                   | $b = 1.07$                           | $\hat{k}$ = 1.109                    | $b = 1.18$                           |
|                           | $\hat{b} = 117.33$                  |                                       | $\hat{b} = 126.65$                  |                                       |
| North of China            | $\hat{k}$ = 1.301                    | $b = 0.65$                           | $\hat{k}$ = 1.299                    | $b = 0.68$                           |
|                           | $\hat{b} = 169.65$                  |                                       | $\hat{b} = 160.08$                  |                                       |
| The total of the eight areas | $\hat{k}$ = 1.152                   | $b = 0.95$                           | $\hat{k}$ = 1.149                    | $b = 0.95$                           |
|                           | $\hat{b} = 137.68$                  |                                       | $\hat{b} = 135.55$                  |                                       |
| Mainland and Taiwan areas | $\hat{k}$ = 1.011                    | $b = 0.99$                           | $\hat{k}$ = 1.009                    | $b = 0.99$                           |
|                           | $\hat{b} = 105.97$                  |                                       | $\hat{b} = 107.26$                  |                                       |
Figure 2: 3D image of the global catalog with the depth.

Figure 3: $b$ value curve of the global catalog (limit level: 4.0).

Figure 4: $b$ value curve of the global catalog (limit level: 5.0).
We draw the curves of shape parameters $\hat{k}$ and $b$ values of each subduction zones with the horizontal direction of $b$ values and vertical direction of shape parameters $\hat{k}$.

From Figure 10, we can see that $\hat{k}$ is always greater than 1.0 which is consistent to the unimodal state of the density function curve. When $b$ values change near 1.0, shape parameters also change near 1.0. For the subduction zones with large changes of $b$ values, shape parameters change obviously.

We draw the curves of scale parameters $\hat{b}$ and $b$ values of each subduction zones with horizontal direction of $b$ values and vertical direction of shape parameters $\hat{b}$.
From Figure 11, we can see that scale parameters \( \hat{b} \) are in fluctuating state with the changes of \( b \) values. There is no correlation between the \( b \) values of the G-R law and the scale parameters \( \hat{b} \) of Weibull distribution.

4. Conclusions

We contrast the data in the China earthquake catalog according to different time intervals and areas. From the results, we can see that the shape parameters \( \hat{k} \) increase with the years increased (only with the magnitude lower limit of 4.0). The conclusions are correct or do not need to be proven with a lot of calculations and facts. We will develop this part in the near future.

During the process of the hypothesis testing, we equally divide the time intervals for the convenience of calculation which are considerable discrepancy between the fault intervals of the engineering. So we think it is necessary to divide
the earthquake time randomly and then carry out the hypothesis testing of Weibull distribution. Thus, the conclusions will own actual meaning and implications of science.

The paper calculates $b$ values and draws the figures of $b$ values of the subduction zones. The paper draws 3D images of typical subduction zones and calculates parameters of Weibull distribution of the subduction zones with enough data.

The result of this paper is very close to the conclusion of seismology, which verifies that the model hypothesis is correct and feasible.

For the further relationship of Weibull distribution parameters and $b$ values, we will carry out in the following study.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

It is declared by the authors that this article is free of conflict of interest.

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