Research on Faults Slip Rate in Weihe Basin based on GPS Data

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Abstract. Based on the GPS data from 2001 to 2011 in Shaanxi Province, a three-dimensional geometric model of faults in Weihe Basin is constructed. Based on the deep fault dislocation model, the present slip rate of main faults in Weihe basin is studied. The results show that: (1) The place with large GPS fitting residual is located at the junction of two faults. (2) The slip rate inversion of most faults is consistent with the geological results, but the slip rate of some faults is quite different from the geological results, and even the movement mode changes. (3) In general, the activity of faults in Weihe Basin is relatively weak. Relatively speaking, the current tensile slip rates of Weihe fault, Chang’an-Lintong fault and eastern segment of northern Qinling fault are relatively high, which are (1.20 ± 0.87~1.69 ± 1.24) mm/a, 2.54 ± 0.94 mm/a, 0.63 ± 1.00 mm/a, respectively.

1. Introduction
The Weihe Basin is located between the Ordos block and the Qinling orogenic belt, and its formation and structural characteristics are directly affected by the tectonic activities of the Ordos block and the Qinling orogenic belt. At the end of the Mesozoic, the Ordos block and the Qinling orogenic belt suffered long-term denudation and flattening, making the Weihe Basin and its north gradually plain. Since the Cenozoic, due to the influence of the Himalayan movement, the Weihe Basin rift has been subject to the northeastward interaction of the Qinghai-Tibet block and the southwestward direction of the North China block. At the front end of the contact part of the Ordos block and the Qinling orogenic belt, a nearly dustpan-shaped Weihe River gradually formed basin. The fault depression process of the Weihe Basin shows non-uniformity in time and space, which is embodied in the relative rise and fall of the main fault blocks. The Weihe Basin belongs to a fault block that is strongly twisted and tilted from south to north. A number of secondary fault blocks can be further divided into the periphery and inside of the basin. Research shows that the central part of the Weihe Basin is the deepest twisted zone in the basin, and its east, west, south, and north boundaries are all composed of stepped normal faults sloping toward the middle of the basin. The southern boundary is the Huashan north margin fault, Weinan fault, Lishan north margin fault, Chang'an-Lintong fault and Qinling north margin fault (middle section). The northern boundary is formed by the Weihe fault and the Kouzhen-Guanshan fault, and the eastern and western boundaries are respectively formed by the Zhongtiaoshan fault and the Qishan-Mazhao fault [1].

The research on active faults in the Weihe Basin began in the late 1950s, and the initial work was mainly the exploration of neotectonic movements. In the late 1960s, due to the intensification of seismic activity in mainland China, geoscience scientists focused their attention on seismic activity research. From the 1970s to the 1990s, geoscientists also studied the repetitive activity cycle of
seismogenic faults, and successively studied the seismic hazards of the Huashan Piedmont fault and the Lishan northern margin fault in the eastern Weihe Basin. In recent years, geoscientists have studied the activity of the main faults in the Weihe Basin based on geological prospecting, geophysical prospecting and other methods [2-9], and relatively few studies on the activity of faults have been carried out using spatial geodetic methods [10-12]. Therefore, this article attempts to use GPS, a high-precision space monitoring technology to study the slip rate of the main faults in the Weihe Basin. By studying the current slip rate of the main faults in the Weihe Basin, to provide a basis for the determination of potential earthquake dangerous areas in the future.

2. Data processing
The GPS data used in this article comes from the observation data of the Shaanxi Province GPS Observation Network from 2001 to 2011. Use high-precision GPS data software GAMIT/GLOBK for data processing. The data processing steps are: (1) Use GAMIT software to calculate the baseline solution for each single day to obtain the H file required for GLOBK calculation; (2) Use GLOBK software for comprehensive adjustment Calculate, get the WGS-84 geocentric rectangular coordinates of each point; (3) Use the GLOBK software to calculate the Velocity field of the GPS Stations. The specific parameter settings are shown in Table 1.

| Processing Model | Model parameters | Processing Model | Model parameters |
|------------------|------------------|------------------|------------------|
| Reference frame  | ITRF2008         | Number of Zenith | 13               |
| Epoch interval   | 120s             | Ionospheric delay| LC-HELP          |
| Maximum of epochs| 720              | Data filtering   | AUTCLN           |
| Cut-off height angle | 10°           | Light pressure model | BERNE            |
| Baseline processing | Relax solution  | Satellite orbit constraint | 10^-8 (20cm) |
| Satellite clock error | Precision Ephemeris | IGS coordinate | X:5cm Y:5cm Z:5cm |
| Receiver clock error | Pseudorange    | GPS coordinate   | X:1m Y:1m Z:1m   |
| Tropospheric Error | Saastamoninen   |                  |                  |

3. Inversion model
In this paper, the Okada dislocation model is used to study the fault slip rate. The classic expression of the dislocation model is as follows: The displacement of a certain point caused by the sliding (strike-slip, tilt-slip) of a rectangular geometric surface in the elastic body is proportional to the sliding amount of the sliding surface. The scale factor is uniquely determined by the relative position of the
point and the sliding surface, the geometric dimensions of the sliding surface, the inclination angle, the
depth and the properties of the elastic medium, the specific model formula can be found in Okada
classic literature [13]. If there are multiple rectangular sliding surfaces underground, the displacement
caused by a certain point on the surface is the superposition of the displacement of the point caused by
the respective sliding of these rectangular geometric surfaces. In this article, the fault zone is regarded
as a series of closed faults on the upper fault planes, and a series of “fault sections” that extend
“ininitely” and move freely on the lower fault planes. The rectangular plane of each fault section can
not only have different scales and dip angles, but also have different lock depths, dislocation rates and
dislocation modes [14-15].

The "deep fault dislocation theory" is widely used to explain the
relationship between the high-precision surface deformation field directly obtained by GPS and other
geodetic methods and the deep movement of active structures. [16-17].

We will use the elastic semi-infinite space fault dislocation model to establish the relationship
between the crustal deformation field of the Weihe Basin and the slip rate of the active faults. First of
all, we need to reasonably model the main faults in the area, that is, on the basis of collecting,
summarizing and analyzing previous research results, each main fracture is divided into a series of
"rectangular pieces" with the upper part locked and coupled and the lower part freely dislocated.
Among them, each rectangular piece is given initial parameters such as spatial position coordinates,
inclination, inclination, locking depth, strike-slip, and tilt-slip rate, the specific initial model
parameters are shown in Table 2.

4. Calculation results

4.1. Inversion strategy

Based on the three-dimensional geometric model of the main faults in the Weihe Basin established
above, each fault section is assigned the rate estimated by the geological method. Through the
semi-infinite space elastic dislocation theory, we can use forward modeling to uniquely calculate and
determine each a three-dimensional velocity vector on a GPS observation point. Conversely, if the
dip-slip rate of all or part of the faulted section is taken as the unknown parameter of the model, the
best fit of the GPS velocity field through the three-dimensional deep fault dislocation model can
determine the best estimate of the motion rate of each faulted section. In this paper, the
above-mentioned ideas are used for inversion calculation. The following strategies are used in actual
inversion:

(1) Based on the fault velocity obtained by the predecessors using geological and geophysical
methods as the initial inversion value.

(2) In the inversion process, in order to overcome as much as possible the trade-off effect caused by
the strong correlation between multiple parameters in the overall inversion process, the fault section
for which the geological rate has been estimated, we take the geological estimate as the initial value of
the corresponding inversion parameter, and assign the corresponding medium error to reflect its
reliability. For those fault sections with reliable geological rate, the motion parameters are treated as
“quasi-known” and given tight constraints. For those fault sections where the degree of research is not
high, the slip rate value is disputed or not yet known, the rough estimate is taken as the initial value,
and loose constraints are imposed.

(3) In order to overcome the difference between the theoretical velocity field of the regional 3D
depth fault dislocation model and the GPS velocity field reference frame, we allow the model velocity
field to be able to translate and rotate freely as a whole during the inversion and fitting.

(4) For the end of the fault, if only considered according to the fault dislocation model, the uplift
distortion will occur due to the forced termination of the fault dislocation. In fact, the uplift distortion
of the fault end is not clearly observed. One possibility is that the dislocations at the fault end are
absorbed by the diffuse plastic deformation. Therefore, in the fault model used for inversion, if there is
a GPS station near the end of the fault, the plastic absorption at the end can be approximated by
extending the fault properly.
On the premise of following the above-mentioned basic research strategy, based on the regional fault geometry model and the semi-infinite space elastic body deep fault dislocation model, we best fit the GPS velocity field, and obtain the minimum fitting residual error by continuously adjusting the model parameters. Through multiple inversion calculations, the slip rate of the main faults in the Weihe Basin is finally obtained. The inverted fault slip parameters are shown in Table 3 and Figure 3. On this basis, the forward model calculated the GPS velocity field and compared it with the actual GPS, as shown in Figure 1 and Figure 2.

Table 3. Inversion results of slip rate of main faults in Weihe Basin

| Fault name             | Segment   | Geological results (mm/a) | Inversion results (mm/a) |
|------------------------|-----------|---------------------------|--------------------------|
| Qishan-Mazhao          | whole     | -0.02~0.08                | 0.24 ± 0.89              |
| Guguan-Guozhen         | whole     | -0.02~0.08                | 0.14 ± 0.94              |
| Taoyuan-Guichuanshi    | whole     | -0.02~0.08                | -0.11 ± 0.94             |
| Northern of Qinling    | Western   | -0.20~0.40                | -1.2 ± 1.21              |
| Changan-Lintong        | Eastern   | -0.20~0.40                | -0.63 ± 1.00             |
| Weihe                  | Western1  | -2.00~2.40                | -2.54 ± 0.94             |
|                       | Western2  | -0.04~0.18                | -1.20 ± 0.87             |
| Huashan                | whole     | -0.21~0.64                | -0.37 ± 0.95             |
| Kouzheng-Guanshan      | whole     | -0.12~0.76                | -0.27 ± 0.89             |
| Hancheng               | whole     | -0.12~0.79                | 0.03 ± 0.93              |
| Shuangquan-Lintong     | whole     | -0.09~0.12                | 0.48 ± 0.92              |
| Lishan                 | whole     | -0.08~0.20                | -0.31 ± 0.96             |
| Western of Huashan     | whole     | -0.08~0.20                | -0.15 ± 0.92             |

Figure 1. Comparison of the measured and simulated GPS velocity fields in the Weihe Basin

4.2. Result analysis
(1) It can be seen from Figure 1 and Figure 2, which the model inversion results are in good agreement with the actual GPS results. The fitting residuals of GPS station displacement rates are mostly less than 1mm/a, which is basically close to the average GPS observation accuracy. But there are some areas with larger fitting residuals, which are the junction of the Longxian-Qishan-Mazhao fault and the Weihe fault, and the junction of the Chang’an-Lintong fault and the northern Qinling fault. These two
regions may be affected by boundary effect factors, whether there are other influencing factors, more detailed research is needed in the next step.

(2) According to Table 3 and Figure 3, the Taoyuan-Guichuanshi fault in the west of the Weihe Basin, the Chang'an-Lintong fault in the middle of the Weihe Basin, the Weinan fault, the Lishan northern margin fault, the Huashan western margin fault, and the Huashan piedmont fault in the east of the Weihe Basin, In the Kouzhen-Guanshan fault in the north of the Weihe Basin, the current slip rate inverted by the model is relatively close to the slip rate obtained by geological means, respectively -0.11 ± 0.94 mm/a, -2.54 ± 0.94 mm/a, -0.37 ± 0.95 mm/a, -0.31 ± 0.96 mm/a, -0.15 ± 0.92 mm/a, -0.72 ± 0.97 mm/a, -0.27 ± 0.89 mm/a, where the symbol "-" (minus) indicates the tension type tilt-slip, and the symbol "." (minus) appears below has the same meaning. Although there may be some problems with the slip rate of these faults, it can at least explain that the geometric models of these faults are closer to the real situation.

(3) It can be seen from Table 3 and Figure 3, which for the Qinling north piedmont fault and Weihe fault (western section), the current fault slip rate inverted by the model is quite different from the fault slip rate obtained by geological means. The slip rate of the fault is (-0.2~0.4) mm/a, and the slip rate
obtained by inversion in this paper is (-0.12 ± 1.21 ~ -0.63 ± 1.00) mm/a. The slip rate of the Weihe fault (western section) obtained by geological means is (-0.04 ~ -0.18) mm/a, and the slip rate obtained in this paper is (-1.20 ± 0.87 ~ -1.69 ± 1.24) mm/a. What caused this obvious difference needs further research. In addition, according to the inversion results of this paper, the current slip rates of the Longxian-Qishan-Mazhao and Guguan-Guozhen faults located in the Longxian-Baoji fault zone are contrary to the results of geological research. Geological methods show that the two faults are positive. The faults are in nature and have left-lateral strike-slip characteristics, but the inversion results show that the two faults are thrust slips, with slip rates of 0.24 ± 0.89 mm/a and 0.14 ± 0.94 mm/a respectively. Similarly, the research results of the Hancheng fault and Shuangquan-Linyi fault located in the eastern part of the Weihe Basin are also contrary to the geological research results, both faults exhibit thrust properties, with slip rates of 0.03 ± 0.93 mm/a and 0.48 ± 0.92 mm/a.

5. Discussion and Conclusion

5.1. Discussion

According to the research results of this paper, the slip rates of each fault obtained by the inversion are different from the geological research results. The reasons for this difference are as follows: Firstly, the model in this paper is a simplification of the complex fault system. The processing method in this article is to merge or delete some similar fractures, which still has a certain deviation from the real fracture distribution. In addition, the geological rate is generally for a specific fault, but the result of this article is the superposition of the slip rate of multiple faults, so the inversion slip rate will deviate from the geological result. Secondly, GPS data result is the result of crustal deformation in the past ten years, while the fault slip rate obtained by geological means is often the result of a hundred years or longer scale. Therefore, the slip rate inverted based on GPS data is different from the long-term average slip rate of faults obtained from geological investigations, and some results are even contrary to those obtained by geological means. Finally, due to the limitations of field geological work, not all segments of the fracture can obtain reliable results. In addition, the results obtained by different researchers are also different, which will also cause differences between the inversion results and the fault slip rate obtained by geology.

Because the results obtained in this paper are different from those obtained by other methods, further research is needed. Firstly, establish a denser and more reasonable distribution of GPS data constraints, and obtain a GPS velocity field with higher resolution. Secondly, according to the previous research results, a more refined three-dimensional geometric model of fault is established. The established model is more consistent with the actual fault distribution, and the selected geometric parameters are more reasonable. Finally, we will try to combine with numerical simulation technology, use a variety of methods to carry out comprehensive research, and conduct more in-depth analysis and discussion of the research results.

5.2. Conclusion

Based on the current GPS velocity field in the Weihe Basin, this paper constructs a three-dimensional geometric model of the main faults in the region, and uses the deep fault dislocation model to invert the fault slip rate. Then we get the following conclusions:

(1) The research results show that, the reliability of fault slip rate inversion based on GPS data constraints, which closely related to the rationality of the fault geometry model and the accuracy of the GPS velocity field. The inversion result has nothing to do with the selection of GPS reference frame, but is closely related to the initial slip rate given to the model.

(2) The inversion results of most fault slip rates are in good agreement with the geological results. However, the Qishan-Mazhao fault and Guguan-Guozhen fault in the western part of the Weihe Basin, the Hancheng fault and Shuangquan-Linyi fault in the eastern part of the Weihe Basin, the inversion results are contrary to the geological results. The inversion results of the northern Qinling fault and Weihe fault are quite different from the geological results.
(3) At the intersection of several faults, the GPS rate calculated by the model is quite different from the GPS rate measured, which may be related to the boundary effect of the fault.

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