Earthquake mechanism analysis of cross-faults system of Zhangjiakou-bohai fault belt in North China

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Abstract North China is one of the earthquake-prone areas and Zhangjiakou-bohai belt is one of the main seismic tectonic belt in North China. There are many cross-faults in the belt and strong earthquakes occur at the intersection of faults. In order to explore the fault behavior and strong seismic mechanism of cross-fault system, we establish 3D finite element models to simulate the sliding activity of faults under the regional tectonic environment.

1. Introduction
Conjugated faults are one of the most common fault distribution patterns. There are many seismic areas existing intersecting conjugate seismogenic faults in Chinese mainland, such as Sichuan-Yunnan rhombic block, North China Plain and other areas. Double-shocks or group earthquakes related to dislocation of conjugate active fault often occur in these areas [1].

Zhangjiakou-bohai belt is one of the main seismic tectonic belt in North China. It is mainly composed of NNE and NWW faults(Fig.1). Small and medium-sized earthquakes are dominant on the NWW faults, strong earthquake occurred mainly on the NNE faults. For example, the main fracture surface of Xingtai earthquake (M7.2) in 1966 is a right-handed tension and torsion fault with strike about N30\degree E, however, the distribution of seismic sequences show there are also two NW dense zones with a length of more than 30 km, except the NE zone. On basis of this, some scholars put forward the concept of seismogenic structure and seismic-control structure, NW Zhangjiakou-Ninghe fault is called seismic-control structure, which mainly plays the control role, and a series of NE or NNE faults are called seismogenic structures [2].

Many scholars [3,4] have discussed the relationship between cross-fault, block activity and earthquakes through physical experiments. In order to explore the mechanism of strong earthquakes of cross-fault system in North China, 3D finite element dynamic models are established to simulate the dynamic process of fault behavior under long-term tectonic loading.
2. Model Establishment

Taking the tectonic form of cross-fault of Zhangjiakou-bohai fault belt in North China as the research subject, 3D finite element models with single NE fault and NE and NW cross-faults are built after simplification, as shown in fig.2. According to similar principles, we set the model size as 100m×100m×20m to characterize the cross-faults system. The fault strike in single fault model is N30°E and in cross-faults system model are N30°E and N60°W, respectively. The faults in model are about 60m. Faults in models are all erect ignoring the impact of fault dip because most of the faults in research area are high dip angle.

![3D finite models with single NE fault (left) and with NE and NW cross-faults (right)](image)

According to the research results of crustal medium structure in North China, the medium parameters in models are set as shown in Tab.2.

| Depth (km) | Density (kg/m³) | Poisson ratio | Elastic modulus | Viscosity coefficient | Friction coefficient |
|-----------|-----------------|---------------|-----------------|-----------------------|---------------------|
| 20        | 2600            | 0.25          | 7.1e10          | 10^{31}               | 0.4                 |
3. Boundary Constraints
The spatial distribution map of focal mechanism solution in North China calculated by FOCMEC method [5] shows most of the earthquakes are strike slip earthquakes. According to research of Zhang Hongyan, et al [6], the direction of stress spindle in Zhang-Bo fault belt has the trend of clockwise rotation from the NEE of northwest end to near EW of southeast end. Average stress spindle in the eastern segment rotates clockwise and is still near EW direction.

The Zhang-Bo fault belt and its adjacent areas have a whole trend moving towards SE direction. And the movement rate of GPS stations in the whole Zhang-bo zone and its adjacent areas is relatively small, the velocity of components E between 0~3 mm/a account for 90% of the total; that of components N direction are concentrated between 1~3 mm/a, accounting for 93%. In term of movement, with the exception of some points around Beijing and Tianjin moving to E or NE direction, all other sites within the study area move to the SE direction. Study on GPS observation data in North China by Shen et al. [7] reveals the left-handed sliding rate with (1.8±1.0) mm/a in Zhang-bo fault belt. Research of Jin Honglin et al. [8] based on the Savage one-dimensional dislocation model shows the Zhang-bo belt has a left-handed slip rate of about 2.0 mm/a. The results of Chen Changyun et al. [9] on the motion characteristics of each segment in Zhang-bo belt show that the motion rate of Zhang-bo belt is low, general not greater than 2 mm/a.

On basis of above researches, we establish the boundary constraints and loading mode (Fig.3). There are two load steps. Step 1: UZ of bottom is fixed, UX of eastern boundary is fixed and UY of southern boundary is fixed, a certain pressure is applied on the northern and western boundary to make the model in the background stress state. Step 2: The other boundary conditions remain the same except that the western boundary is constrained by a displacement rate instead of pressure.

4. Simulation results
Two times of contour map of three displacement components of two models in loading step 2 are given as below.

4.1. Single NE fault model
Figure 4 shows that with the loading of displacement rate, stress on the NE fault accumulates continuously until the right-handed strike slip occurs.

4.2. Cross-faults system model

Figure 5 shows that with the loading of displacement rate, the left dislocation occurs first on the NW fault, then accompanying with the ongoing displacement rate loading, the right-handed strike slip occurs on the NE fault. The NE fault dislocation is obviously larger than NW fault dislocation.

5. Conclusion

From the mechanical origin, the NNE-NE fault belt reflects the dextral shear mechanism, and the NW-NWW fault belt reflects the left-handed shear mechanism, which is suitable for the crustal stress field in North China. And their distribution direction is close to the two maximum conjugate shear stress directions in the stress field.
The cross fault system simulation shows that under the existing tectonic loading conditions of the model, the left-handed dislocation of NW fault occurs earlier than that right-handed dislocation of NE fault. And strong earthquakes are easy to occur at the intersection of faults.

The effect of friction coefficient of fault on sliding behavior is that the time of starting sliding at sliding point lags with the increase of friction coefficient.

Acknowledgements
Thanks for the fund support of Earthquake Tracking project (2020010503) and Earthquake Technology Spark Plan project (XH19001Y).

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