Simulation of the effects of fault creep on the stress field of its neighbor faults

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Abstract

In the 2D model including three faults, the variation of stress field is simulated by 2D finite element method when one of the faults creeps with time, and the relation between fault creep and damaged area is discussed under the Coulomb's Failure Criterion. The results show that the extreme high stress regions always stand on the ends of the faults and migrate with fault creep. The variation of stress near the ends of creeping fault is larger than that in other fault ends. If the region with high stress variation is taken for the place where more "earthquake precursors" occur, the ends of creep fault are the places. The results also show that damaged regions are near the ends of the faults, and the damaged region near the creeping fault grows up with fault creeping. In other words, the seismic level near the ends of the creeping fault is higher than that near the ends of other faults.

Introduction

The observation, experimentation and theory of fault creep have been studied world-wide after the observatory fact of fault creep near Hollister, California since 1960's[1]. Fault creep is divided into two types: static creep and intermittence creep. The former is a symmetrical and slow, and the latter is asymmetrical. Generally, the velocity of fault creep is several centimeters a year[2]. The creep of San Andreas Fault is asymmetrical, and the creep displacement is about several millimeters[3]. Some fault creeps are related to earthquakes. The creep before an earthquake is called precursory creep. The precursory creep begins from several minutes to several hundred days before an earthquake. Studies on the stress styles of Xingtai, Tonghai, Luhuo and Songpan large earthquakes in China also showed that dislocations occurred before the main quakes and they had crept before the main quakes[4]. Zhang Y.Z.[5] studied the fault parameters of Tangshan Ms7.8 earthquake in China by elastic dislocation theory. Her result reveals that the creep fault is about 8km from 1969-1975, and dislocation of strike and dip is 104cm and 8cm, respectively. Hence the average velocity of strike creep and dip creep is 18.6cm/a and 1.4cm/a, respectively. Fault creep was also recorded after an earthquake on the fault directly related to the earthquake, and its velocity attenuates logarithmically for several years. There were other researches about fault creep in China[6]-[8].

According to rock mechanic experiment, in the sample including preexist cracks, fracture spreads along the ends of the preexist cracks. Taking the spreading of preexist cracks as fault creep, which weakens the strength of medium, Shi, Y.L., et al.[9] simulated the stress variation caused by fault creep with 2D finite element method, and gave some explanations for earthquake anomalies migrating from outside to epicenter. In this paper, we consider a model including three faults, among which one of the faults creeps with time. By 2D finite element method, the variation of stress and strain caused by fault creep is simulated. Based on the simulating result, the feature of space and temporal evolution of precursory field is discussed. Potential damaged area caused by fault creep is also circled out under Coulomb's Failure Criterion.

Theory and Model

1) Theory

According to rock mechanic experiment, the medium of rock is dilatant and non-elastic when the rock comes near failure. Y.L.Shi[9]-[10] gave the constitute relations of dilatant rock with five independent elastic coefficients:

$$
\begin{aligned}
\sigma_{11} &= c_{1111}\varepsilon_{11} + c_{1133}\varepsilon_{22} + (c_{1111} - 2c_{1212})\varepsilon_{33} \\
\sigma_{22} &= c_{1133}\varepsilon_{11} + c_{3333}\varepsilon_{22} + c_{1133}\varepsilon_{33} \\
\sigma_{33} &= (c_{1111} - 2c_{1212})\varepsilon_{11} + c_{3333}\varepsilon_{22} + c_{1111}\varepsilon_{33} \\
\sigma_{12} &= c_{2323}\varepsilon_{12} \\
\sigma_{23} &= c_{2323}\varepsilon_{23} \\
\sigma_{23} &= c_{1212}\varepsilon_{13}
\end{aligned}
\tag{1}
$$

where c_{ijkl} (i,j,k,l=1,2,3) stands for elastic coefficient in different direction, ε_{ij} denotes strain and σ_{ij} denotes stress.

In another expression of the constitute relations between stress and strain, the five independent elastic coefficients are E_1, E_2(Yang's modulus), ν_1, ν_2 (Poisson's ratio), and G(shear modulus). So we can obtain equivalent E_1, E_2, ν_1, ν_2 and G from c_{ijkl} [10].

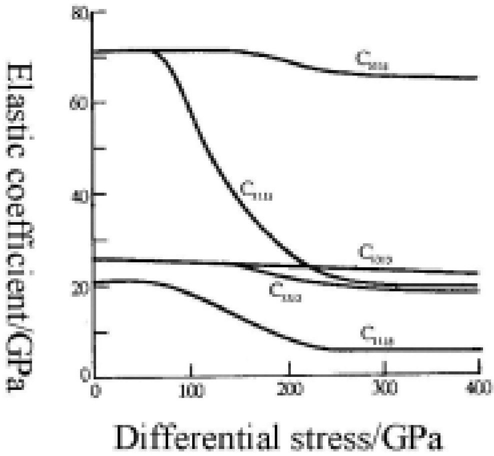

Figure 1 Variation of elastic coefficients with differential stress

The variation of c_{ijkl} with differential stress was obtained by rock mechanic experiment[10], as shown in figure 1. The stress field is simulated by 2D finite element method[10].

2) model

In this paper, we consider the effects of a creeping fault on the stress variation near neighbor faults, and a simple model including three faults is set up with the size of 100km×100km(figure 2). The model is divided into 50 × 50=2500 elements, and 51 × 51=2601 nodes. Fault Ⅰ is the creeping fault with the length of 5km and the width of 2km. Fault Ⅱ and Ⅲ is with the same size and the same quality, excluding that the strike of fault Ⅱ is vertical to that of fault Ⅰ and the strike of fault Ⅲ is parallel to that of fault Ⅰ.

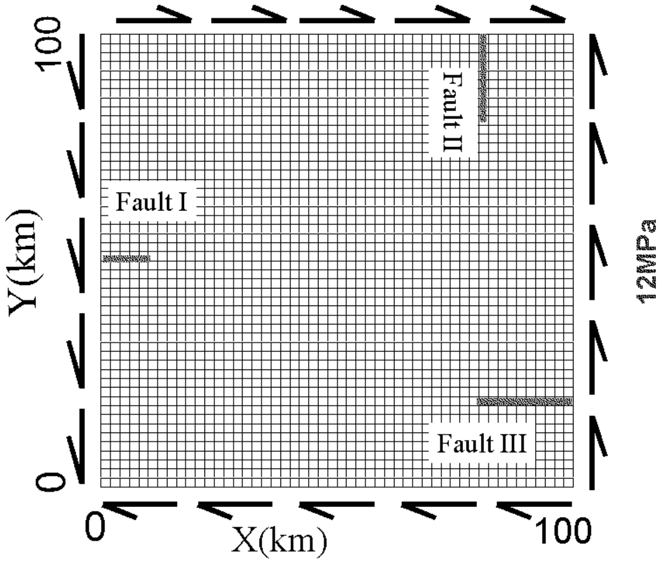

Figure 2 Sketch of the model

Parameters of the faults and the block are listed in table 1.

Table 1 Parameters of the model

	E_1(GPa)	E_2(Gpa)	ν_1	ν_2	G(GPa)
Block	61.8	61.8	0.22	0.22	25.3
Fault Ⅰ	6.2	6.2	0.33	0.33	0.003
Fault Ⅱ and Ⅲ	31.2	31.2	0.26	0.26	0.03

Boundary force is equivalent to pure shear stress shown in figure 2.

Results and analyses

1) Initial stress field

Figure 3a and 3b give the contours of mean stress ($\bar{\sigma} = \dfrac{\sigma_1 + \sigma_2 + \sigma_3}{3}$) and maximum shear stress respectively when fault Ⅰ has not crept.

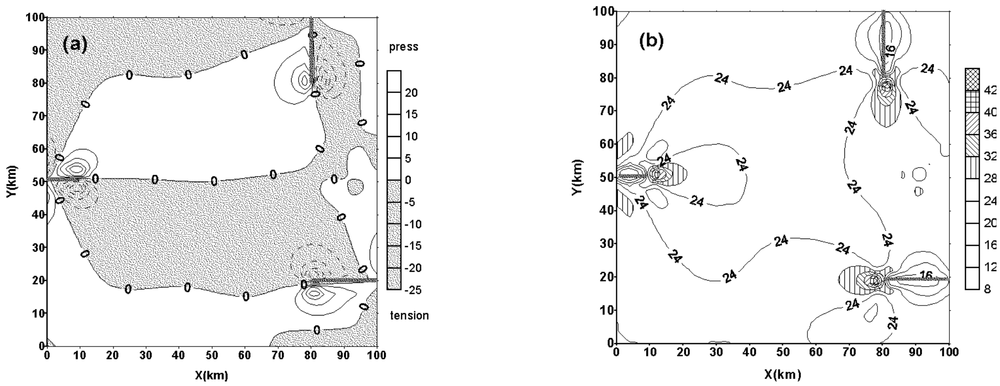

Figure 3 Initial stress distribution

(a). mean stress (b). maximum shear stress

Shadows in figure 3a represent expanded regions, and the others represent compressed regions. In the simple model, the distribution of expanded regions and compressed regions is much complex. Mean stress concentrated to the ends of each fault. The area between fault Ⅰ and fault Ⅱ is expanded, while the area between fault Ⅰ and fault Ⅲ is compressed.

Figure 3b shows the distribution of maximum shear stress. The regions with highest maximum shear stress locate at the heads of the three faults, while those with lowest maximum shear stress locate at the tails of the three faults.

Summarily, heterogeneous medium of this model cause the non-well distribution of stress.

2) Variation of stress cause by fault creep

When fault Ⅰ is weakened and begins to creep, we can obtain stress distribution similar to that in figure 2, except the peak value of mean stress and maximum shear stress grow larger. Here we concern the variation of stress caused by fault creep..

Figure 4 show variation of mean stress when the end of fault Ⅰ moves for 6km(figure 4a), 16km(figure 4b), and 30km(figure 4c). Shadows in figure 3 represent regions with decrease of mean stress. Compared with figure 3a, mean stress near fault Ⅰ changes a lot while those near fault Ⅱ and fault Ⅲ has little change. As fault Ⅰ creeps, fault Ⅱ is expanded and fault Ⅲ is compressed, and mean stress near the head of fault Ⅰ grows larger and larger. In other words, when a fault creeps, it makes the fault vertical to it expand and the fault parallel to it compress.

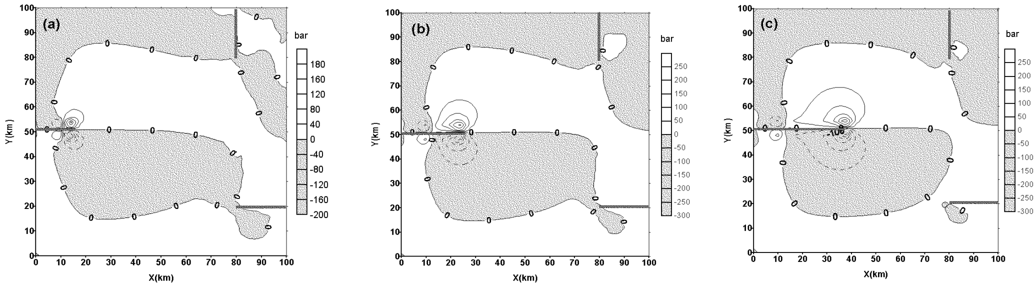

Figure 4 Variation of mean stress caused by moving of the end of fault Ⅰ

(a). moving for 6km (b). moving for 16km (c). moving for 30km

Figure 5 show variations of maximum shear stress when the end of fault Ⅰ moves for 6km(figure 5a), 16km(figure 5b), and 30km(figure 5c). Compared with figure 3b, maximum shear stress near fault Ⅰ changes a lot while those near fault Ⅱ and fault Ⅲ has little change. As fault Ⅰ creeps, maximum shear stress around its head increase while that around its tail decrease. As fault Ⅰ creeps long and long, variation of maximum shear stress near fault Ⅱ and fault Ⅲ is little and little.

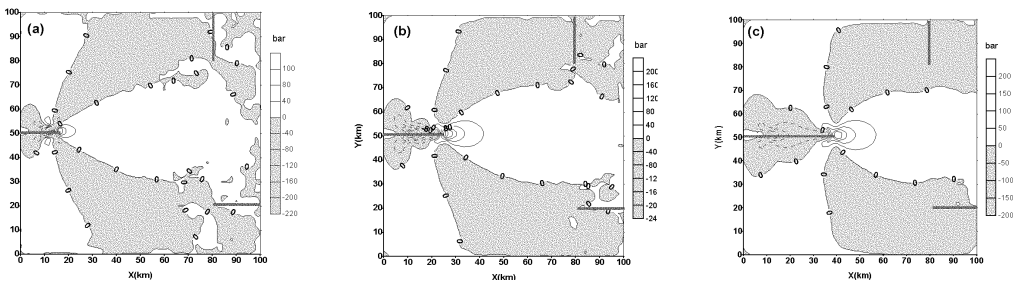

Figure 5 Variation of maximum stress caused by moving of the end of fault Ⅰ

(a). moving for 6km (b). moving for 16km (c). moving for 30km

If we take the region where stress changes a lot as the place where earthquake anomalies occur, figure 4 and figure 5 tell us that areas near the head and tail of the creeping fault are the places. A few earthquake anomalies could also be observed in areas near the heads of other neighbor fault.

3) Damaged areas caused by fault creep

If we take Coulomb's Failure Criterion to judge the damaged area, shadows in figure 6 are damaged areas due to the creep of fault Ⅰ. Figure 6a shows damaged areas when the end of fault Ⅰ moves for 6km. The damaged areas are near the heads of the three faults. Compared with figure 3a, the damaged areas locate in the expanded area. As fault Ⅰ goes on creep, damaged area near its head grows lager and larger and migrates with fault creep, while those near the heads of fault Ⅱ and fault Ⅲ have little change. In the viewpoint of seismic activity, fault creep could bring larger earthquakes near its head than those near the heads of other neighbor faults, and epicenter of earthquakes near the head of creeping fault migrates with its creeping.

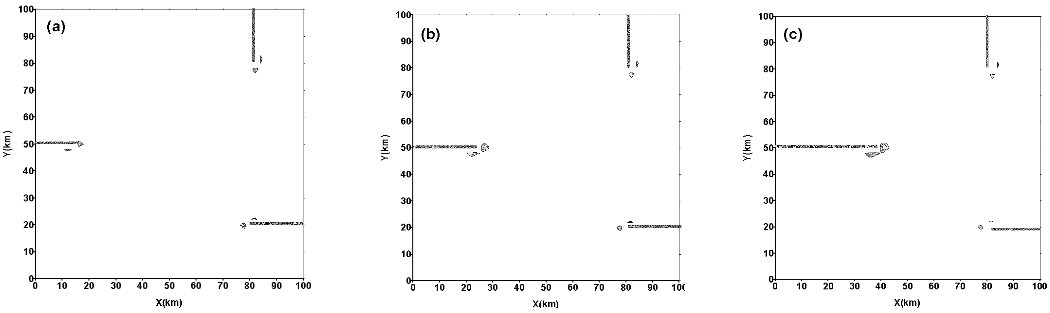

Figure 6 Damaged areas when the end of fault Ⅰ moves(by Coulomb's Failure Criterion)
(a). moving for 6km (b). moving for 16km (c). moving for 30km

There are some interesting phenomena that might have some relationship between seismic activity and fault creep. For example, nearly two months before the Vietnam Ms7.0 earthquake on June 24, 1983, moderate earthquakes in Yunnan province, China migrated from north-west to south-west[11], as shown in figure 7. In this figure, we can also find that the magnitudes of these moderate earthquakes grow up gradually, which is similar to the result of our model.

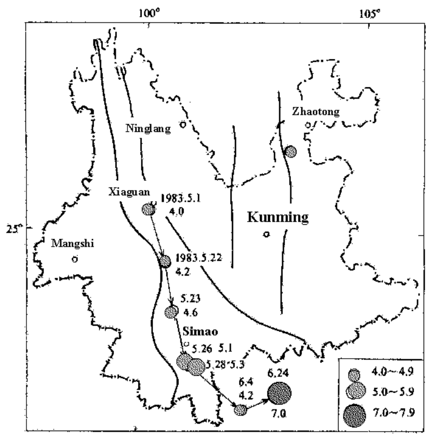

Figure 7 Earthquakes migrated directionally before Vietnam 7.0 earthquake in 1983

Summary and Conclusions

Fault creep exists in crust deformation, and it might be a result of strengthening of stress or weakening of medium. In this paper, we take fault creep as the result of the medium weakening, and obtain the following conclusions:

1) In the model including three faults, high stress regions locate at the ends of these faults. When one of the faults creeps, the simulation shows that the highest additional stress regions

locate at the ends of the creeping fault. Between the fault parallel to the creeping fault and that vertical to the creeping fault, and the higher additional stress regions locates at the ends of the former fault;

2) If fault creep could cause large earthquake, then the earthquake precursors might appear at the head and the tail of the creeping fault. A few earthquake precursors might appear at the heads of the other faults;

3) Cracks might occur at the ends of the three faults, and the cracks locate in the expansion region near the heads of the faults. As one of the fault creeps, damaged area near the head of the creeping fault grows larger and larger, and it migrates with fault creep.

In our simple model, some interesting phenomena are obtained, such as earthquakes migrate directionally, creeping fault has stronger effect on the parallel fault than the vertical one. Actually, our simple model does not match the real complex crust block, there are many further research to do in our next project

Acknowledgments

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