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Numerical Simulation of Stress evolution and earthquake sequence of the Tibetan Plateau

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The India-Eurasia's collision produces N-S compression and results in large thrust fault in the southern edge of the Tibetan Plateau. Differential eastern flow of the lower crust of the plateau leads to large strike-slip faults and normal faults within the plateau. From 1904 to 2014, more than 30 earthquakes of $Mw > 6.5$ occurred sequentially in this distinctive tectonic environment. How did the stresses evolve during the last 110 years, how did the earthquakes interact with each other? Can this knowledge help us to forecast the future seismic hazards? In this essay, we tried to simulate the evolution of the stress field and the earthquake sequence in the Tibetan plateau within the last 110 years with a 2-D finite element model. Given an initial state of stress, the boundary condition was constrained by the present-day GPS observation, which was assumed as a constant rate during the 110 years. We calculated stress evolution year by year, and earthquake would occur if stress exceed the crustal strength. Stress changes due to each large earthquake in the sequence was calculated and contributed to the stress evolution.

A key issue is the choice of initial stress state of the modeling, which is actually unknown. Usually, in the study of earthquake triggering, people assume the initial stress is zero, and only calculate the stress changes by large earthquakes – the Coulomb failure stress changes (Δ CFS). To some extent, this simplified method is a powerful tool because it can reveal which fault or which part of a fault becomes more risky or safer relatively. Nonetheless, it has not utilized all information available to us. The earthquake sequence reveals, though far from complete, some information about the stress state in the region. If the entire region is close to a self-organized critical or subcritical state, earthquake stress drop provides an estimate of lower limit of initial state. For locations no earthquakes occurred during the period, initial stress has to be lower than certain value. For locations where large earthquakes occurred during the 110 years, the initial stresses can be inverted if the strength is estimated and the tectonic loading is assumed constant. Therefore, although initial stress state is unknown, we can try to make estimate of a range of it.

In this study, we estimated a reasonable range of initial stress, and then based on Coulomb-Mohr criterion to regenerate the earthquake sequence, starting from the Daofu earthquake of 1904. We calculated the stress field evolution of the sequence, considering both the tectonic loading and interaction between the earthquakes. Ultimately we got a sketch of the present stress. Of course, a single model with certain initial stress is just one possible model. Consequently the potential seismic hazards distribution based on a single model is not convincing. We made test on hundreds of possible initial stress state, all of them can produce the historical earthquake sequence occurred, and summarized all kinds of calculated probabilities of the future seismic activity. Although we cannot provide the exact state in the future, but we can narrow the estimate of regions where is in high probability of risk. Our primary results indicate that the Xianshuihe fault and adjacent area is one of such zones with higher risk than other regions in the future. During 2014, there were 6 earthquakes ($M > 5.0$) happened in this region, which correspond with our result in some degree.

We emphasized the importance of the initial stress field for the earthquake sequence, and provided a probabilistic assessment for future seismic hazards. This study may bring some new insights to estimate the initial stress, earthquake triggering, and the stress field evolution .