Numerical Investigation of Fault Bend Influence on Earthquake Nucleation and Development

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Abstract

Earthquakes have been recognized as resulting from a stick-slip frictional instability along the faults between deformable rocks. From both practical observations and laboratory experiments, the geometry of the fault significantly affects the faulting process. A 3-dimensional finite element code for modeling the nonlinear frictional contact behavior between deformable rocks with the node-to-point contact element strategy has been developed and applied here to analyze the fault bend influence on the earthquake nucleation process.

Introduction

Earthquakes have long been recognized as resulting from a stick-slip instability along the faults between deformable rocks although the rupture process itself is generally complex due to the nonuniform distribution of stress and strength on faults. King and Nabelek [1] examined the source processes of the following eight events: the 1966 Parkfild earthquake (Ms=6.5), the 1973 Luhuo earthquake (Ms=7.5), the 1975 Lice earthquake, the 1976 Tangshan earthquake, the 1976 Caldiran earthquake, the 1979 Coyote Lake earthquake (MS=5.7), the 1980 E1 Asnam earthquake and the 1984 Morgan Hill earthquake (Ms=6.1), and concluded that the initiation and/or termination of earthquake rupture was usually controlled by geometrical irregularities of faults such as fault bends. Kato et al [2] experimentally investigated the effect of fault shape on the rupture process of stick-slip using a granite sample with a pre-cut fault that was artificially bent and drew the same conclusion. From the above practical observations and laboratory results, the geometry of the faults significantly affects the faulting process and must therefore be considered in earthquake research.

The finite element method is now widely applied to science and engineering problems. Several in-house and commercial codes were applied to simulate specific phenomena related with earthquakes ([3,4] and references thereafter). As for the numerical investigation of the effect of fault geometry on the earthquake process, only a few results have been reported. Oglesby et al [5] analysed the effect of fault geometry on the dynamic propagation behaviour of the Chi-Chi earthquake with the prescribed nucleation and the slip-weakening friction law, in which the fault was assumed to dip with a constant angle. To further investigate the occurrence of the earthquake and to predict it in the future, an arbitrarily shaped contact element strategy, named as the node-to-point contact element strategy proposed with a static-explicit algorithm by the authors (e.g. [6]), was previously applied to model the nonlinear friction contact behaviour between deformable rocks with stick and finite nonlinear frictional slip [3,4]. This paper will focus on investigating the influence of a fault bend on the stick-slip instability using the above algorithms and to help lay a foundation for the further research on the earthquake nucleation process and earthquake prediction.

Numerical Investigation of the Fault Bend Effect on Rupture Process

To investigate the fault geometry influence on the stick-slip instability, a typical fault bend model is analyzed here. Figure 1 shows the geometry, the boundary conditions and the meshes along a cross section. Here all the materials have the same properties: density $\rho = 2.60\, g/cm^3$, Young's modulus $E=44.8\ GPa$ and Poisson's ratio $\gamma = 0.12$. As for the loading conditions, two loading stages are applied here: firstly, the pressure along the surfaces A and B are loaded to 10 MPa, then while sustaining this pressure on surface A, all nodes on surface B are moved in the x-direction at $Vx=-0.001mm/sec$. The widely applied rate- and state-dependent friction law is used here to describe the behaviour of the fault interface using the following parameters: $\mu = 0.60 + (0.010 - 0.025) ln(V / 0.001)$.

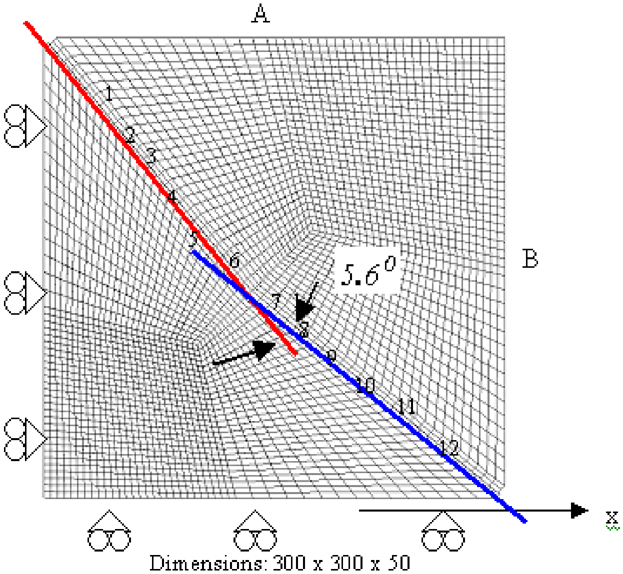


Fig. 1 Mesh and boundary conditions used in the simulations.

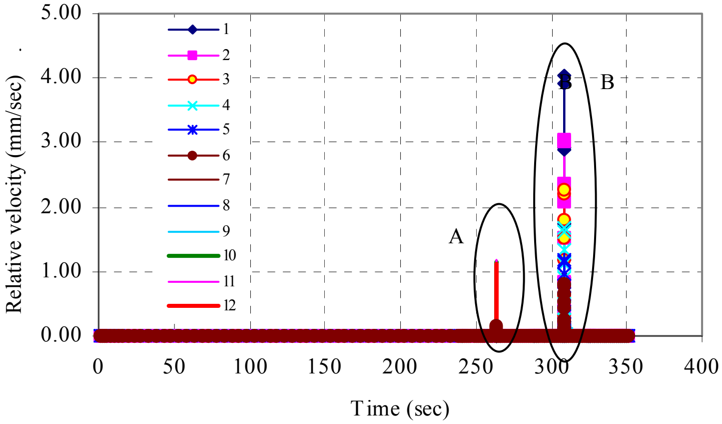
Generally speaking, there are two major kinds of earthquakes: interplate earthquakes (e.g. many earthquakes in Japan and California) and the intraplate earthquakes (e.g. as in Australia and for most earthquakes in China). Here, the influence of the fault bend on the stick-slip instability for both the intraplate and the interplate cases is investigated.

Interplate Case

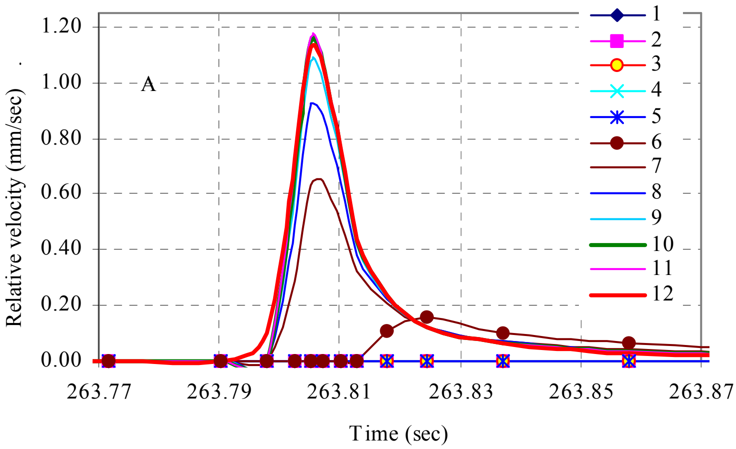
For this case, all the conditions are the same as described above. The effect of the fault bend on the variation of the relative velocity and the normal contact force along the interface at the second loading stage is respectively shown in Figures 2 and 3.

Intraplate Case

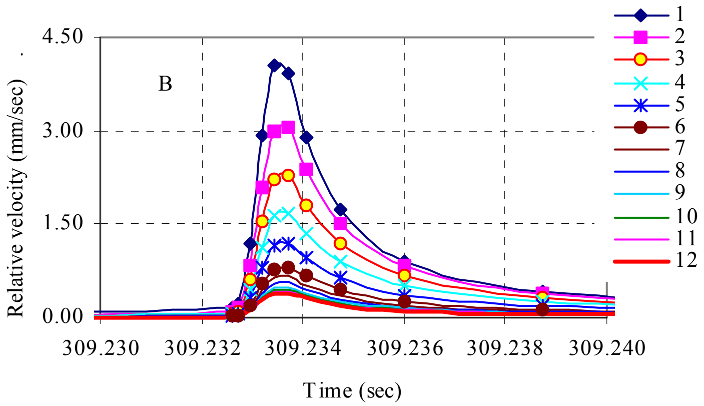
For this case, there exists no relative motion along the interface at the both ends as shown in Fig.1. This can be easily achieved using the 'stick' algorithm in the code. All other conditions are the same as above. Figures 4 and 5 respectively show the effect of the fault bend on the variation in the relative velocity and the normal contact force at the second loading stage.



(a)



(b)



(c)

Fig.2 The relative velocity variation. (a). During the total process; (b). Magnification of A; (c). Magnification of B.

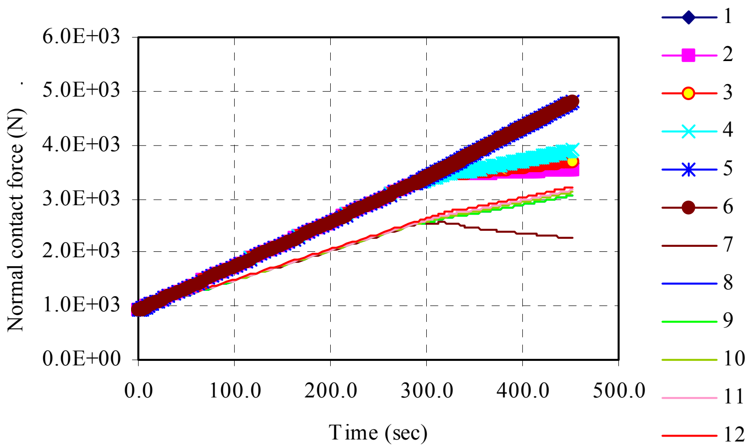
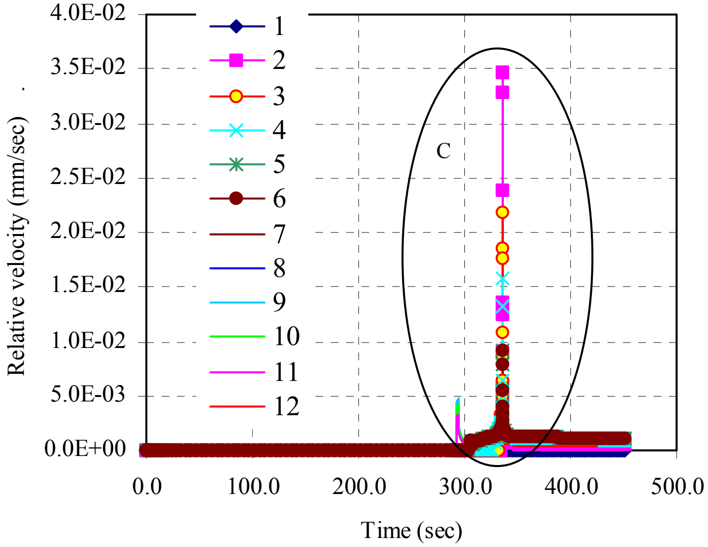


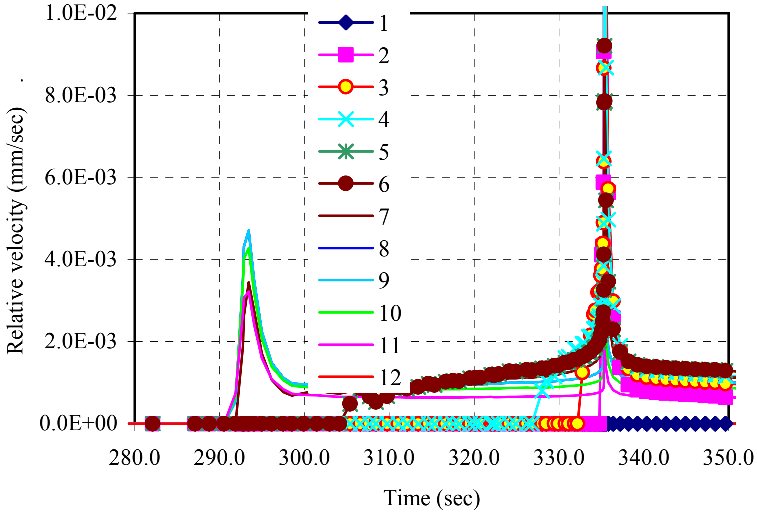
Fig.3 The normal contact force distribution.

Discussion and Conclusions

The influence of a prescribed fault bend on the relative slip velocity, the normal contact force and the transition of stick-slip state between the deformable rocks for both the intraplate and the interplate cases is investigated. The numerical results demonstrate that: (1) There exist two stages of the slip process (i.e. the stick-slip instability) for both the intraplate and the interplate cases; (2). The stick-slip instability initiates on the lower fault segment and stopped near the fault bend, then restarted near the fault bend on the upper fault segment. Furthermore, the first instability only occurs on the lower fault segment while the second propagates along the entire fault. All the above phenomena are mainly due to the nonuniform distribution of the normal contact force as shown in Figures 3 and 5. During the second stage, the normal contact forces along the entire interface rise, but due to the effect of the fault bend, those on the upper segment increase more quickly than those on the lower segment. Hence, the nodes on the lower segment reach the slipping state earlier. The above numerical results also indicate close qualitative agreement with the experimental results from Kato et al [2].



(a)



(b)

Fig.4 The relative velocity variation (a). During the total process; (b). Magnification of C.

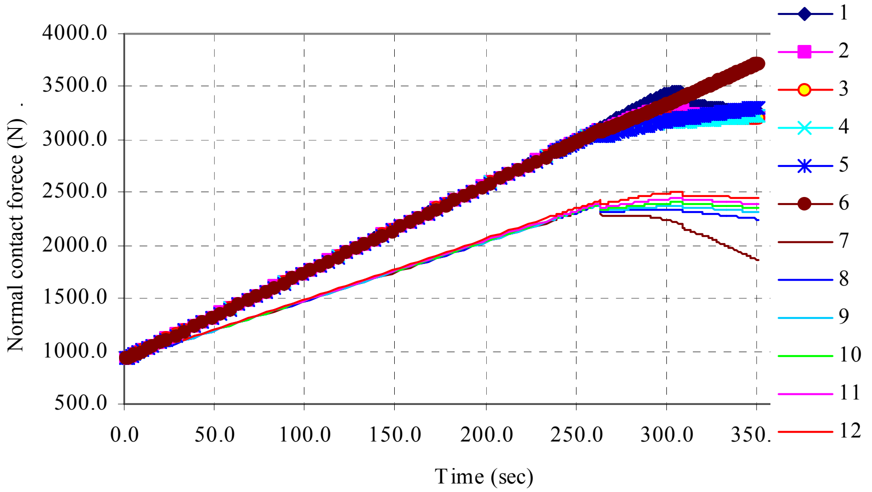


Fig.5 The normal contact force variation.

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