Effective frictional behavior of a heterogeneous rate-and-state fault

Pierre Dublanchet, Pascal Bernard and Maxime Godano

Institut de Physique du Globe de Paris, 1 rue Jussieu 75005 Paris, France.

Contact:dublanchet@ipgp.fr, bernard@ipgp.fr, godano@ipgp.fr

1 - Introduction

In this study, we analyze the seismic activity generated by a heterogeneous fault zone made of a melange of creeping material and brittle asperities. For that, we developed a quasi-dynamic rate-and-state asperity model in which the heterogeneous structure of the fault is concentrated on a single plane containing frictional asperities embedded in a creeping aseismic area. The numerical and theoretical results presented here indicate that the relative proportion of brittle material is an important parameter that controls the regime of seismic activity. When confronted to micro seismic observations, this modeling approach provides important insights into the local fault behavior, as demonstrated here for a particular sequence occurring within the western Corinth rift zone in Greece.

2 - Sources of micro-seismic swarms

Fig. 1 : Left : Seismicity in the Corinth rift 2000-2007, from (Lambotte et al., submitted). Right : Northern sequence (green square in left figure). All the events belong to the same multiplet. Seismic moments $M_o$ are derived from a spectral analysis of $P$ and $S$ wave. from (Godano et al., in prep.).

3 - Asperity model

Critical density of asperity $\rho_a$ and effective friction parameter $A$

The regimes of activity obtained in a rate-and-state asperity model are controlled by the density of asperities $\rho_a = S_{crp}/S_{crit}$ (Dublanchet et al., 2013a). The transition between a regime of uncorrelated activity (Fig. 4 left) and a regime of highly clustered swarms (Fig. 4 right) occurs when the density of asperity exceeds a critical threshold $\rho_a^c$ given by:

$$\rho_a^c = 1 + \frac{\Delta \tau_e}{\mu \Delta v_{sl}}$$

where $\Delta \tau_e \sim 7$ MPa is the average stress drop on the asperities, and $v_{sl} \sim 1$ cm.s$^{-1}$ a radiative sliding velocity. The critical density of asperity threshold is equivalent to an effective friction concept (Dublanchet et al., 2013b): if $A$ is the spatially averaged $a-b$ parameter, we have

$$\rho_a > \rho_a^c \equiv A < 0 \quad \text{effective weakening behavior}$$

$$\rho_a < \rho_a^c \equiv A > 0 \quad \text{effective strengthening behavior}$$

4 - How effective friction controls regimes of seismicity

Fig. 4 : Two different regimes of seismic activity obtained numerically with the asperity model for the distribution of asperities represented in the right and left small panels. Left : friction parameter $a < b$ on the barriers between asperities is such that the density of asperities is sub-critical, that is $\rho_a < \rho_a^c$ (the effective friction on the fault is velocity strengthening). Right : friction parameter $a > b$ on the barriers between asperities is such that the density of asperities is super-critical, that is $\rho_a > \rho_a^c$ (the effective friction on the fault is velocity weakening). From (Dublanchet et al., 2013a).

5 - Effective creep or effective crack?

Fig. 6 : Two end member multiplet models of the multiplet in Fig. 2. (A) : the sources are surrounded by a locked segment. The multiplet area is similar to a crack. (B) : the sources are surrounded by creeping segments.

Fig. 7 : Number of rupture and cumulative coseismic displacement obtained for the crack model (A) of Fig. 6, after 40 years of loading at $v_{sl} \sim 2$ cm.yr$^{-1}$.

Fig. 8 : Number of rupture and cumulative coseismic displacement obtained for the creep model (B) of Fig. 6, after 3.5 years of loading at $v_{sl} \sim 2$ cm.yr$^{-1}$.

6 - Conclusions

The results presented here indicate that the regime of seismic activity generated by a heterogeneous fault is strongly controlled by the density of asperities, or, equivalently, by an average friction parameter. Making use of these concepts in the specific case of micro seismicity recorded in the Corinth Rift, we have demonstrated how this approach allows to constrain local frictional behavior on faults. In particular, we are able to determine whether a localized swarm develops within a crack-like area, or within a creeping segment of fault.

References


Godano, M., Bernard, P., Marsan, D., & Dublanchet, P. in prep.. Geophys. J. Int.