13 Slip Transients, Deficit and Release from Repeating Earthquakes

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13.1 Introduction

To better understand interactions between seismic and aseismic deformation, deep aseismic fault slip rates (Vd) from characteristically repeating microearthquake sequences (CS) (Nadeau and McEvilly, 1999) along the central San Andreas Fault (SAF) were compiled and analyzed. Previous CS based Vd studies have shown that spatial and temporal variations in Vd can be resolved over large contiguous regions, in diverse tectonic settings, and back in time to well before the advent of satellite-based geodesy (e.g., GPS, InSAR) (Nadeau and McEvilly, 1999 and 2004; Bürgmann et al., 2000; Igarashi et al., 2003; Chen et al., 2008). Such studies have also revealed systematics in Vd indicative of slip transients associated with post-seismic deformation, slow-slip events, quasi-periodic slip pulsing, and regions of slip-deficit accumulation.

13.2 Activities

We searched for CSs along a 200 km stretch of the SAF in Central California and identified and compiled a catalog of 343 CSs comprised of 2854 microearthquakes ranging in magnitude from 1.5 to 3.5 and occurring over a 27.333 year period between 1984 and April of 2011 (inclusive). The CSs were located between the approximate southern terminus of the 1989 M6.9 Loma Prieta (LP) and the northern terminus of the 1857 M7.8 Ft. Tejon (FT) earthquakes, and the catalog includes CS activity associated with the 2004 M6.0 Parkfield earthquake (PF) rupture, its aftershock zone, and the aftershock zone south of the LP earthquake rupture.

We used the method of Nadeau and McEvilly (2004) to convert the the locations, times and magnitudes of the CS micro-events to map the time histories of Vd within the study region.

13.3 Findings

Figure 2.29 shows profiles of the CS derived short- and long-term Vd behavior in the study zone in the context of the spatio-temporal distributions of the 1989, M6.9 LP and 2004, M6.0 PF earthquake rupture zones. The locked (inferred rupture) zone associated with the 1857, M7.8 FT earthquake occurs immediately to the southeast.

Moving northwestward from 20 km along the long-term profile (left), a sharp reduction in long-term Vd is observed at ~95 km. This corresponds to the bifurcation of the SAF system into the SAF and the sub-parallel Calaveras fault (not shown) strands. The sum of long-term rates on these strands is comparable to the tectonic plate rate (~3.0 to 3.5 cm/yr), consistent with the sharing of tectonic load release by the strands.

Between 20 and 95 km, no significant difference between long-term Vd before PF (pre-PF) and Vd for the entire study period are observed. However, southeast of 20 km, long-term pre-PF rates are lower and are below the plate rate, indicating slip deficit accumulation. The reduced pre-PF rates are also apparent in the short-term contoured profile. Following PF, short-term Vd increases dramatically in the PF rupture and after-slip zones. By April 2011, long-term Vd southeast to -15 km has caught up to the plate rate. A similar pattern is seen in the LP after-slip zone northwest of ~125km, suggesting a general pattern where slip deficit accumulates and releases both seismically (on rupture zones) and aseismically (on adjacent regions). This has important implications for estimating the dimensions of future earthquake rupture and magnitude from inter-seismic patterns of slip deficit accumulation or paleoseismic observations of fault slip from past earthquakes.

Southeast of -15 km, long-term Vd lags behind the plate rate. Our search also revealed no CSs in the ~35 to -50 km segment that was included in the 1857 FT rupture zone. This suggests considerable seismic and aseismic slip release in a future large event which, if it happened today, would average ~4.5 meters of seismic slip.

13.4 Acknowledgements

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13.5 References


Figure 2.29: Profiles of the short- and long-term Vd behavior in the study zone in the context of the spatio-temporal distributions of the M6.9 LP and M6.0 PF earthquake rupture zones. The locked (inferred rupture) zone associated with the M7.8 FT earthquake occurs immediately to the southeast. Left panel: profiles of long-term Vd (15 km smoothing) along the SAF for the entire observation period (solid black curve with grey fill) and for the period preceding the 2004 PF event (dashed black curve). Thin gray line represents a tectonic plate-rate of 3.0 cm/yr. Right panel: colored/contoured profile of % variations in short-term Vd (0.8 year averaging window) relative to the long-term average (entire observation period). Light gray (yellow) regions show periods when short-term Vd exceeds the long-term average by 20% or more. Dark gray (blue) regions show periods when long-term rate is below average, and intermediate gray (blue-green) regions are those with Vd within +/- 20% of average. Rupture zones of PF and LP events within the study area are black vertical lines, and the slip rate history (in cm/yr.) of a 15 km segment (centered at ~90 km) with nine cycles of particularly periodic aseismic slip-transient pulsing is shown with a white curve.