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New Insights on Rupture Behavior Combining Field Observations with Numerical Simulations

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Seismic hazard analysis relies on forecasting the suite of potential earthquakes within a fault system, however as many individual seismic events have shown us, the size, geometry, and behaviour of coseismic ruptures are more complex than current models generally account for. Propagating ruptures navigate a path through stress changes due to fault geometry and prior rupture history—variables that control whether a rupture halts or grows, along a single fault or many. Collectively, we seek to understand the suite of potential earthquake ruptures on a given fault system based on limited observations of past events and current understanding of rupture physics. In this study, we interrogate the impact of a restraining bend on the Altyn Tagh Fault, western China, in modulating rupture size. Through a comparison of geomorphic and paleoseismic observations to the results of physics-based numerical simulations of dynamic rupture on the fault system, we establish the likelihood of this geometric barrier being breached by a rupture. We measure slip rate gradients and paleoseismic recurrence intervals within the Aksay restraining double-bend, and relate these observations to the number of events and accumulated slip in multi-seismic-cycle numerical models of dynamically propagating ruptures. Geologic results show persistent termination of ruptures at the bend based on spatial declines in slip rate and constraint by unfaulted landforms. Modelling results show that indeed fewer than 1 in 10 ruptures propagate through the bend, but a build-up of residual stresses permit rare large events to rupture through. Agreement of geologic and modelling results allows us to use natural observations to assess the probability of throughgoing rupture at this geometric complexity.

In similar fashion, we can document several complex earthquake ruptures from the past 150 years using multi-scale photogrammetry, and compare the coseismic ruptures with long-term activity within each fault system. By relating known ruptures to longer term behaviour we can assess the rate at which sections of the fault participate in similar ruptures, and thus derive empirical estimates of the probability that rupture jumps particular geometric complexities and fault intersections. By comparing known ruptures to long term slip rates, and comparing slip rates to numerical modelling results, we offer an approach to translate basic geologic observables into probabilistic estimates of whether ruptures stop or proceed at geometric barriers.