Modeling Rupture through the Brawley Seismic Zone Stepover: Can Ruptures Propagate between the San Andreas and Imperial Faults?

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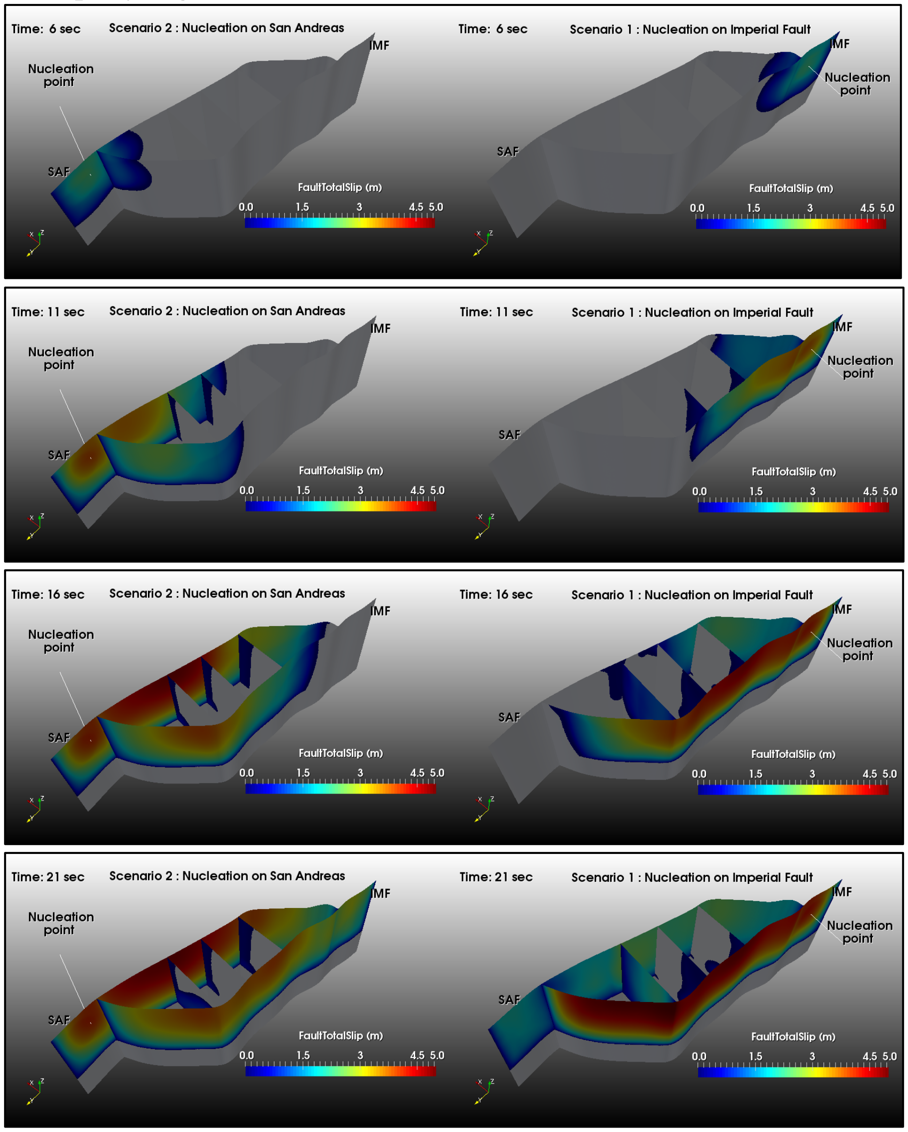
A. Abstract

Paleoseismic observations indicate that the southern San Andreas and Imperial faults (SAF and IF) ruptured at similar times in past earthquakes, suggesting that they may have ruptured together during single events. Modeling of dynamic rupture scenarios that involve the southern SAF and IF suggests that large earthquakes may rupture through this large step-over, depending on rupture directivity and the presence of connecting faults or cross-faults, supporting the paleoseismic observations. Nucleation on the SAF favors rupture of both the SAF and IF in the step-over region, whereas nucleation on the IF ruptures primarily the western (IF) strand of the step-over. We interpret this asymmetry to reflect the geometrical complexity of the system, which leads to dynamic clamping and unclamping of the system at different locations and at different times.

B. SCEC Annual Science Highlights

C. Exemplary Figure



Snapshots of rupture propagation on a 3D fault system with cross faults, modeled after the configuration of the southern San Andreas and Imperial faults. Cross-faults are modeled from the well-defined seismicity lineaments in the Brawley Seismic Zone.

D. SCEC Science Priorities: 4e, 4a, 3e

E. Intellectual Merit: Understanding whether large step-overs between major fault strands will always terminate large earthquake ruptures, or whether certain structural configurations may allow for slip to pass through these complexities is a key question in understanding large earthquake production on California’s system of plate boundary faults. UCERF3 assumes that ruptures can jump steps as much as 5 km in dimension, but some structural configurations may allow for larger jumps. This study models the southern San Andreas-Imperial fault step through the Brawley Seismic Zone to determine whether some structural configurations may allow ruptures to pass through and continue from one fault to the other.

F. Broader Impacts: A great earthquake on the southern San Andreas fault, with surface rupture from Parkfield to the Salton Sea, will cut most major lifelines into southern California, including highways and major water conduits. One major highway that has been considered safe in such an event is the I-8 corridor, as it runs south of the southern terminus of the San Andreas fault. In this study, we consider whether it may be possible that a large earthquake can rupture through the large releasing step that comprises the Brawley Seismic Zone and produce rupture on the Imperial fault. Part of the impetus for this study is the recognition that some large earthquakes on the Imperial and southern San Andreas fault are indistinguishable in timing and could represent large earthquakes that ruptured both fault segments. If so, then all major highways and byways into southern California could be cut by such an event. Also, an undergraduate summer intern, Drew Tulanowski, was trained in producing 3D finite element meshes of the fault systems for the modeling effort, and participated in this research, and post-doc Christos Kyriakopoulos acted as a primary supervisor for Mr. Tulanowski, providing him with experience in training students.

G. Project Publications –This work has been presented at the 2015 SCEC Annual Meeting in September, and it will be presented at the 2016 SSA Annual Meeting in April.

Technical Report: Modeling Rupture through the Brawley Seismic Zone Stepover: Can Ruptures Propagate between the San Andreas and Imperial Faults?

Introduction and Background Although not considered in hazard scenarios, it remains an open question whether rupture could propagate between the southern San Andreas fault (SAF) and the Imperial fault (IF) (Figure 1). From paleoseismology, the timing of the two most recent events along the southern SAF are indistinguishable from ruptures on the IF. The step-over region between the two faults includes Mesquite Basin, a pull-apart between the IF and the Brawley fault zone (BFZ). North of the surface traces of the IF and BFZ, but south of Bombay Beach, microseismicity defines an elongate region known as the Brawley Seismic Zone (BSZ), that stretches NNW to SSE, from Bombay Beach to Mesquite Basin. At depth, microseismicity suggests further structural complexity (Lin et al., 2007; Hauksson et al., 2012), with numerous cross faults. Although no through-going southeastward extension of the SAF or northward extension of the IF or BFZ has yet been identified, and although ruptures are generally considered unlikely to propagate through stepovers

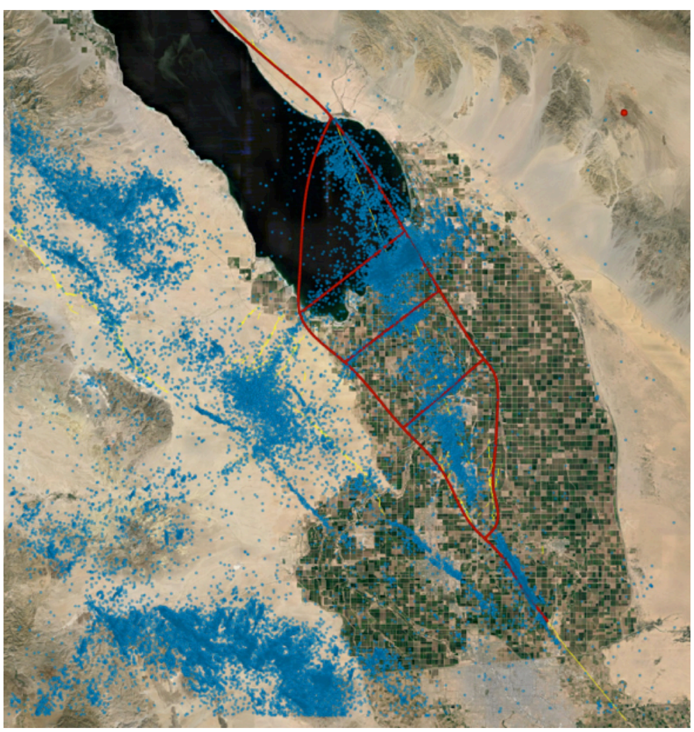


Figure 1. *Local seismicity and modeled fault geometry.*

wider than 4–8 km, dynamic earthquake modeling by Magistrale and Day (1999), Oglesby (2005), and Lozos et al. (2011, 2012) suggests that the detailed geometry of a stepover, including any intermediate strike-slip or linking dip-slip faults, can significantly affect whether a rupture can propagate through the stepover. In particular, some structural complications may allow rupture to propagate through wider stepovers than would be possible in the absence of those complications. This observation, and the indistinguishable timing of past events on the southern SAF and IF, suggest that propagation through the stepover may have happened in the past and may happen again in the future. Considering the lapse time of nearly 300 years since the most recent large southern SAF rupture, consideration of this possibility is in order.

Methods

We use the 3D dynamic finite element code FaultMod (Barall et al., 2009, GJI) to model potential earthquakes on this fault system and determine the likelihood of through-going rupture. The length of the FEM domain is ~100 km. The length of the irregular fault interface is ~83 km and is implemented in the center of this domain. Our modeled fault system is shown in Figure 1 in map view, and in 3D in Figure 2. The final model comprises ~60 million tetrahedral elements with high element density near the simulated rupture interface, but becomes sparser toward the boundaries of the model domain.

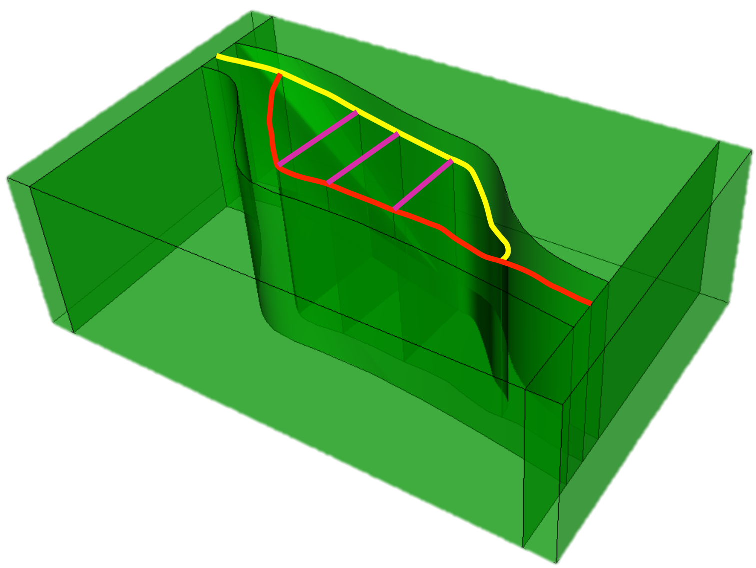


Figure 2. *3D view of modeled fault geometry.*

Results and conclusions

Under the assumption that there are continuous fault structures connecting the southern San Andreas Fault to the Imperial fault, and that these faults are under relatively constant traction conditions, our results indicate that it may be possible for rupture to propagate through the stepover between these faults. Nucleation on the SAF produces roughly equal slip on both strands in the stepover region, while nucleation on the IF produces significantly more slip on the IF strand in the stepover, and rupture almost dies out on the SAF strand. Left-lateral cross faults may possibly aid in rupture propagation by facilitating rupture propagation from the IF to the SAF, as shown in Figure 3. The reasons for this asymmetry between different rupture directivities lies in the mixture of bends and branching angles in this geometrically complex system, which lead to dynamic clamping and unclamping of the system at different locations and at different times.

More work is necessary to fully estimate the likelihood of through-going rupture at this stepover, including examining heterogeneous stress fields, and the possibility of discontinuous fault structures. The goal is to produce models that are consistent with the paleoseismic record and that can give insight into future faulting behavior.

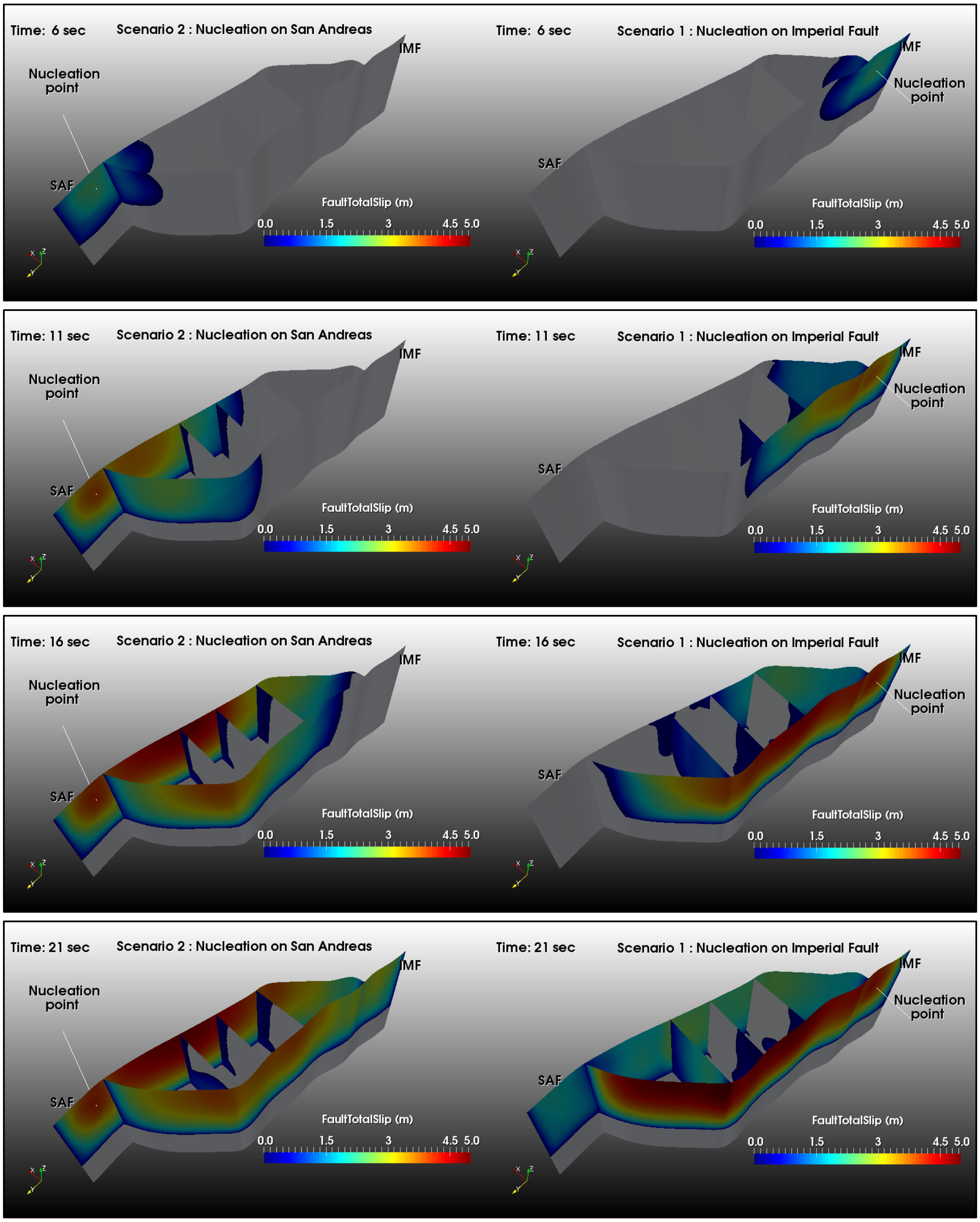


Figure 3. *Snapshots of rupture propagation on 3D fault system with cross faults.*

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