The importance of expanding the Earthquake Center region to include the northern San Andreas fault system

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We suggest that the geographic scope of the future Earthquake Center be expanded to cover the northern San Andreas system up to the Mendocino Triple Junction. This will facilitate improved understanding of fault behaviors and improved hazard estimates for large urban areas in California.

A greater diversity of fault behaviors

Including the major faults of northern and central California in the region of interest of the Earthquake Center would increase the diversity of investigated fault behaviors, leading to a more complete understanding of fault mechanics. In particular, slow-slip phenomena, which have been recognized as potential precursors of recent major ruptures (e.g., Kato et al., 2012; Ito et al., 2013; Socquet et al., 2017), are well established north of the current SCEC natural laboratory (Figure 1). Several of these faults creep along significant portions of their lengths (Weldon et al., 2013). Long-term monitoring of this creep using ‘alignment arrays’ (short baseline triangulation arrays; Lienkaemper et al., 2014) and creepmeters (Bilham et al., 2004) has shown a rich spectrum of time-dependent behavior of these faults in different locations, including continuous creep, episodic creep with different periodicities, and even left-lateral (retrograde) triggered slip (McFarland et al., 2018). Laboratory friction experiments have shown some promise for identifying the lithological associations with creep, and thus for applying lessons learned to other regions (Moore et al., 2018). The central San Andreas fault, which creeps at the surface, also sustains tectonic tremor at lower crustal depths (Shelly, 2017), which are accompanied by slow slip events (Rousset et al., 2019). The underlying geological conditions that facilitate tremor and slow slip are still not well understood; more focused investigation benefitting from excellent field access may illuminate the mechanism, and produce results that may be more broadly applicable (e.g., to subduction zones).

The branching geometries of the major faults in the San Francisco Bay Area provide an excellent natural laboratory to study the physics of fault interactions and multi-segment ruptures. These junctures and the transitions from creeping to locked sections in the SAF system represent some of the most striking “earthquake gates” in the plate boundary zone. Inclusion of the highly geometrically complex and youngest section of the SAF system just south of the Mendocino Triple Junction will enable research aimed at understanding the maturing of transform plate boundaries, and the influence of evolving fault-zone geometry on earthquake characteristics. Finally, studying potential interactions of the SAF system with the adjacent Cascadia subduction zone will provide new insights into stress evolution, triggering relationships and earthquake clustering over a wide range of spatial and temporal scales (e.g., Goldfinger et al., 2008).
**Figure 1:** *(Lower left)* Region of proposed expansion. Faults from the UCERF3 report (Field et al., 2013) are marked as solid lines (gray within the SCEC5 region, brown outside). Red box outlines the San Francisco Bay Area. *(Upper right)* Details of fault complexity and earthquake-associated hazards in the San Francisco Bay Area. Creeping fault segments are indicated in purple; areas of high or very high liquefaction susceptibility (Knudsen et al., 2000) are shown in pink; blue dashed line outlines the Sacramento-San Joaquin Delta area.
A wide array of secondary seismic and aseismic hazards

Several past earthquakes in the San Francisco Bay Area have induced significant secondary hazards, such as widespread liquefaction and landsliding, region-wide. The last major event in the region, the 1989 $M_w$ 6.9 Loma Prieta earthquake, had a short duration for an event of its size due to bilateral rupture and was located well to the south of the major populated areas. Despite these mitigating factors, the earthquake resulted in over 4000 landslides and caused significant building and infrastructure damage due to liquefaction over 100 km away from the epicenter (Clough et al., 1994). Soil conditions in many parts of the Bay Area are conducive to liquefaction, with structures built on fill atop San Francisco Bay muds and old river channels being particularly susceptible. The current priorities of the Earthquake Center do not include a specific focus on the roles of such secondary effects in earthquake hazard and risk, yet they represent a significant amplifier to risk over the expected damage caused by strong shaking. In the recent Haywired scenario, simulating the effects of a magnitude 7 earthquake on the Hayward fault, the inclusion of liquefaction and landslide hazards increased the expected losses by over 16% over shaking alone (Detweiler and Wein, 2018). Several areas of southern California have subsurface conditions conducive to liquefaction or landsliding, including the San Fernando Valley, Los Angeles Basin, Oxnard Plain and Coachella Valley (liquefaction) and the San Gabriel and San Bernardino Mountains (landsliding). Expanding the Earthquake Center to include the northern San Andreas system would draw a sharper focus on the need to investigate such phenomena, and provide a pathway to incorporating such expertise into future research.

In addition to a greater focus on geotechnical hazards, inclusion of the northern San Andreas system and its greater diversity of fault slip behaviors will also facilitate study of post-earthquake hazards. Several recent ruptures on partially creeping faults in northern and central California were followed by rapid shallow afterslip that in some cases equalled or exceeded the largest coseismic slip, such as the 2004 M 6.0 Parkfield (Johanson et al., 2006; Murray and Langbein, 2006) and 2014 M 6.1 South Napa (Hudnut et al., 2014, Floyd et al., 2016). Ongoing postseismic slip represents a significant hazard in its own right, capable of repeatedly breaking fault-crossing infrastructure – in the 2014 South Napa earthquake, roads and a gas pipeline that crossed the source fault were repaired more than once (Kelson and Wesling, 2015). The Haywired scenario, focused on the partially creeping Hayward fault, explicitly included afterslip among the sources of potential infrastructure damage; an assessment of the likely damage to the East Bay water supply estimated that afterslip would be of equal importance to coseismic rupture (Detweiler and Wein, 2018).

A statewide Earthquake Center for investigating statewide earthquake risks

Expanding the geographical scope of the Earthquake Center will allow it to better serve the whole population of California. The greater San Francisco Bay Area is home to over 7 million people, and also to multiple dangerous active faults that have not hosted damaging earthquakes in living memory. The added research focus provided by an Earthquake Center, combined with
the ongoing research by the USGS, CGS and other institutions will enhance our ability to investigate these faults in detail, and thus to forecast more accurately the seismic hazard and risk posed by them. A geographical expansion to the north would benefit all Californians, not just those living in northern or central California. Given the connected nature of the state’s infrastructure lifelines, earthquake hazards that could be considered remote can have a strong impact on the population hundreds of miles away.

One example is the Sacramento-San Joaquin Delta. The water supply for over 25 million Californians (the majority living in southern California) and 4 million irrigated acres of farmland is transported through the Delta area, representing a significant fraction of California’s drinking water, and of the national agricultural capacity. Damage to the levee system within the Delta, by seismic shaking, liquefaction or surface rupture, could imperil that water supply, potentially with state- and nation-wide consequences. As much as 4 mm/yr of tectonic shortening may be localized within the Delta area (Prescott et al., 2001) where there exists several identified blind fault structures (e.g. Wong et al., 2010). Relatively little is known about the seismic potential of these faults, compared with the strike-slip faults to the west. The enhanced focus that an Earthquake Center could provide, to this and to other fault-crossing lifelines, would help to characterize such hazards and their associated risks with greater accuracy, and benefit all Californians and the nation.

**Uniting the coverage of UCERF, the Earthquake Center and community models**

The Uniform California Earthquake Rupture Forecast (UCERF) is the premier study of statewide earthquake hazard in California, a report that is widely used by policy makers, utilities and industry to guide earthquake mitigation planning efforts and to assess seismic risk. The Earthquake Center has been a major contributor to UCERF, and the research underpinning it, over the past two decades (e.g. Field et al., 2008; Field et al., 2013). There is, however, a mismatch between the coverage area of UCERF (which includes the whole San Andreas system), and the availability of community models developed within the Earthquake Center that provide input for UCERF calculations (which currently focus on southern California only). There will be synergistic and logistical benefits for aligning the areas of coverage of both entities.

A major activity within the last two iterations of the Earthquake Center (i.e. SCEC4 and SCEC5) has been the development of consensus community models for important hazard assessment inputs, such as fault geometries and slip rates, seismic velocities, the geodetic deformation field, and more. The level of detail is significantly higher in some of these community models than in the corresponding versions used in UCERF. By expanding Earthquake Center activities to include northern and central California, we could unify the methodologies, resolutions and applications of such community models to include the whole UCERF area, potentially leading to more accurate and detailed seismic hazard assessments.
Expanding and refreshing the researcher base of the Earthquake Center

While researchers and students from institutions outside of southern California have always been engaged in SCEC, an expansion to the larger San Andreas system plate-boundary zone will grow and diversify the Earthquake Center community. This will provide new intellectual stimulus, enrich the research enterprise and community engagement, and increase the impact of the collaboratory.

References

Kelson, K. and J. Wesling, 2015, Appendix B: Supplemental to surface fault rupture associated with the M6.0 South Napa earthquake of August 24, 2014, in Bray, J. et al. eds,


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