Introduction

Our knowledge of slip rates along Los Angeles faults is constrained to limited paleoseismic observations of exposed faults [e.g. Clark et al., 1984, McNeilan et al., 1996, Grant et al., 1997], and indirect fault modeling efforts for subsurface faults [Davis et al., 1989; Shaw and Suppe, 1996, Cooke and Southall, in review]. Dip slip rates along buried faults in the Los Angeles Basin have been inferred from two-dimensional kinematic reconstructions using geometric rules [Davis et al., 1989; Shaw & Suppe, 1996] and from two-dimensional forward models based on continuum mechanics [Cooke and Southall, in review]. Although the mechanical models that use fault geometry inferred from kinematic reconstructions show promising correlation with paleoseismic slip-rates, these two-dimensional studies have not considered the important strike-slip component of deformation along the transpressional Los Angeles fault system. Additional data is needed in order to constrain three-dimensional fault configuration and slip rates; we are fortunate to have SCIGN data available for this purpose.

Our main goal is to better assess the hazards associated with buried faults within the Los Angeles basin. We present our work to date on estimating fault geometry and slip rates by combining kinematic models of geodetic data from SCIGN with continuum mechanics models. SCIGN data gives us the deformation within the Los Angeles basin with unprecedented spatial resolution. However, to date the SCIGN data has only recorded interseismic strain accumulation requiring us to develop a method for effective comparison of mechanical models of interseismic strain accumulation and SCIGN data. This methodology as well as the slip rates from the preliminary three-dimensional mechanical model is presented in this report.

Slip Rates From Mechanical Models

A preliminary three-dimensional model of the fault configuration in the Los Angeles Basin has been constructed (Fig. 1) based on previously published arrays of two-dimensional cross-sections [Davis et al., 1989; Oskin et al. 2000; Shaw and Suppe 1996; Wright, 1991] and in consultation with John Shaw of Harvard University. This model of the basin extends southwest to the Palos Verdes peninsula, north to the foothills of the Santa Monica Mountains and east to the Repetto and Whittier Hills. Fault configuration is constrained by seismic reflection data, well control and predictions of fault geometry using kinematic fault-related fold theory and associated growth strata [Davis et al., 1989; Oskin et al. 2000; Shaw and Suppe 1996]. The boundary element method (BEM) numerical model Poly3D [Thomas, 1994] is used to assess the response of this fault model under geodetically determined horizontal contraction [Feigl et al., 1993] in order to simulate conditions in the Los Angeles Basin.

Poly3D calculates the surface uplift rates associated with fault slip. Calculated uplift rates accurately predict certain elements of topography in the Los Angeles area (Fig. 2), including the Whittier Hills to the east, the Hollywood Hills to the northwest, and the Palos Verdes uplift. For example, paleoseismic evidence indicates uplift in Palos Verdes Hills of 0.3-0.4 mm/year [McNeilan et al., 1996], closely matching model results in this area. Because this model does not include erosion, regions of the model with moderate uplift (<0.2 mm/yr) are not expected to correlate with areas of current uplift. However, predicted regions of moderate uplift may also result from inaccurate subsurface fault configuration.

Using Poly3D to estimate slip on faults in the LA basin, the calculated slip sense and slip magnitude closely match much of the available paleoseismic data (Table 1;Fig. 3). Discrepancies between the model results and paleoseismic data include (1) reported predominant strike-slip component of slip on Palos Verdes Fault [McNeilan et al., 1996], (2) reported right-lateral strike-slip on Whittier Fault [Petersen & Wesnousky, 1994] and (3) reported dip slip on the Raymond fault (Petersen & Wesnousky, 1994). Although the model produces a greater dip:strike slip ratio than that detected by McNeilan et al [1996], this ratio may vary along the fault trend. Additionally, the model under-predicts strike-slip rates on the Whittier fault. The failure to match paleoseismic data from the Whittier fault may be due to lack of
understanding of the relationship among Whittier and nearby blind thrusts. The third discrepancy is the overprediction of dip-slip along the Raymond fault. The modeled fault slip rates along the Raymond are comparable to the Santa Monica and Hollywood faults, which have similar trend and orientation as the Raymond fault. Dip-slip along the Raymond fault could be reduced within the model by including additional faults parallel to and nearby this fault.

Three models with varying dips of detachment faults (0˚ and 10˚) and the Elysian Park thrust (45˚ and 50˚) were examined to test the sensitivity of the slip rates to small changes to fault geometry (Fig. 3). Results from all models are similar and paleoseismic data cannot be used to differentiate among these plausible alternatives.

Methodology for Comparison of Interseismic Strain Accumulation

Comparison of mechanical 3D model results and geodetic data requires consideration of the different time scales and processes incorporated in each. Surface velocities produced by the mechanical BEM code due to slip along faults in the Los Angeles basin reflect deformation over geologic timescales incorporating many earthquake events. These velocities represent what we refer to as the long-term or geologic strain pattern. SCIGN velocities are not expected to resemble the geologic deformation since they have (at the time this report was written) only measured recent interseismic elastic strain accumulation within the Los Angeles basin.

The standard method for comparing geologic slip rates with geodetic data is to assume that during the interseismic period of the earthquake cycle, faults are locked within the seismogenic crust and slipping at a constant rate below this depth [Savage and Burford, 1973]. The constant creep of material beneath the seismogenic crust is expressed on the surface as interseismic deformation measurable on short time scales. Over longer geologic time scales, this same creep of material beneath the locking depth gives rise to coseismic fault slip within the seismogenic crust. Consequently, the creep rate inverted from geodetic data can correlate to slip rates in the seismogenic crust for isolated faults. Studies of elastic strain accumulation along vertical strike slip faults have favorably compared geologic with interseismic rates using this technique [e.g., Shen et al., 1996, Bourne et al., 1998, Savage et al., 1999]. With more complicated fault geometry that includes intersecting faults, subhorizontal detachments and dipping faults, the continuation of fault surfaces below the seismogenic depth becomes kinematically problematic.

We have developed a two-step method that will allow us to estimate interseismic surface velocities from the mechanical three-dimensional models of Los Angeles basin faults by estimating the long term secular velocities at the locking depth and simulating geologic creep of material below the locking depth using a horizontal crack. We can estimate the long-term secular velocities at the locking depth from Poly3D (Fig. 4a) by incorporating a horizontal crack weak in shear at the base of the seismogenic crust. The deformation on this crack will then be prescribed along the base of an unfaulted elastic crust, with a thickness equal to the estimated seismogenic crust (Fig. 4b). An infinitesimally thin horizontal crack at the locking depth serves to decouple the upper seismogenic crust from lower portions of the elastic half-space. This approach extends from that used by Shen et al [1996] and by passes the obstacles of fault interaction for regions of complex three-dimensional faulting.

Future work includes testing of this method’s effectiveness for estimating interseismic velocities at the surface. The test simulates an isolated vertical strike-slip fault for which there are successful standard models for comparison. Once we are able to reproduce the analytical model of interseismic strain along a vertical strike slip fault, we will proceed with estimating the interseismic strain from the more complicated LA basin fault geometry and comparing this strain to SCIGN data.

Conclusion

The calculated slip-sense, magnitude of slip and uplift rates from the 3d mechanical model closely match much available paleoseismic data. The close correspondence with paleoseismic is not considered significant beyond an indication that such models may be able to provide a general sense of the magnitude of slip to be expected on faults that are not exposed. The model also accurately captures relative movements along faults in this system, with the exception of underpredicting (1) dip-slip on the Whittier fault and (2) strike-slip component on the Palos Verdes fault as well as overprediction of dip-slip along the Raymond fault. The variation among alternative models was not sufficient to allow identification of the most plausible model based on paleoseismic data. A methodology for comparing
SCIGN data with predictions of interseismic strain accumulation at the earth’s surface from the mechanical models has been developed. Once tested, the methodology will serve to further validate the subsurface fault configuration and slip rates in the Los Angeles basin.

Abstracts related to this work

References
Suppe, J., R.E. Bischke, and J. Shaw, Regional map view and cross-sectional determination of fault geometry and slip for blind thrusts in populated areas of southern California, Southern California Earthquake Center SCEC Annual Meeting, 1992.
Table 1: Model slip for 10˚ detachments and 45˚ dipping Elysian Park thrust

<table>
<thead>
<tr>
<th>Fault</th>
<th>Dip-Slip (mm/yr)</th>
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Figure Captions

Figure 1: A three-dimensional fault model for the Los Angeles Basin was constructed from planar and curving surfaces made up of triangular elements. Fault surface locations were extrapolated from published two-dimensional maps and cross-sections. Locations of exposed faults are based on Wright [1991]. Subsurface faults are based primarily on Shaw and Suppe [1996]. Additional blind thrust surfaces are based on Oskin and Dolan [2000] (Elysian Park) and further work by Plesch and Shaw [personal communication, 2000].

Figure 2: Calculated vertical surface displacements (uplift) in mm/yr. Regions of uplift greater than 3 mm/yr include the Whittier Hills, the Hollywood Hills and the Pals Verdes Hills.

Figure 3: Rates of dip-slip (a) and strike-slip (b) along faults in the Los Angeles basin for which paleoseismic data are available. Altering the dip of detachment faults and the dip of the Elysian Park thrust did not significantly change the slip rate of the faults. The model results closely match the paleoseismic slip rates with exception of underestimation of dextral slip along the Whittier fault and overestimation of dip-slip on the Raymond fault. Paleoseismic data taken from: 1) McNeilan et al, 1996; 2) Clark et al, 1984; 3) Dolan et al, 1997; 4) Petersen and Wenousky, 1994; 5) Freeman et al, 1992; 6) Grant et al, 1997; 7) Suppe et al, 1992 and 8) Rockwell et al, 1992.

Figure 4: A) First step of analysis: geologic strain accumulation which includes both coseismic fault slip and interseismic bulk strain. Determine displacements along horizontal crack weak in shear at seismogenic locking depth due to remote contraction and fault slip. The horizontal crack serves to decouple the seismogenic crust from the underlying elastic half-space. Tips of the crack extend well beyond the study area to minimize influence of crack tip deformation. B) Second step of analysis: surface expression of interseismic strain due to geologic strain accumulation below the brittle crust. Prescribed displacements on the horizontal crack are transmitted through the locked elastic crust (no slip events).
Fault Legend

- Grey: Redondo Canyon, Palos Verdes
- Light grey: detachment system
- Yellow-green: THUMS-Huntington Beach
- Pink: Newport-Inglewood
- Light blue: connector
- Purple: Santa Monica, Hollywood & Raymond (east to west)
- Blue: Los Angeles, Elysian Park, Coyote Hills, Santa Fe (north to south)
- Green: Whittier

Figure 1.

Figure 2.

Figure 3.

Figure 4.