Use of Stress Drop Models to Interpret Geodetic Measurements at Loma Prieta

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Objective

Surface deformation due to slip in the earth's crust is typically interpreted using the well-known dislocation method. Here, we employ an alternative approach in which slip regions are approximated by planar zones of prescribed stress drop (rather than relative displacement, i.e., dislocation). By applying this approach to the observed coseismic geodetic data associated with the 1989 Loma Prieta, California, earthquake, we are able to obtain estimates for the slip induced stress drop and moment, and the critical energy release rate at the termination of rupture.

Results

The Loma Prieta event is modeled as shear slip of an inclined elliptical crack embedded in an elastic half-space. The shear stress drop is assumed to be uniform with a component $\Delta\tau_s$ along the strike and a component $\Delta\tau_d$ along the dip direction of the fault. The resulting slip is calculated using the method of Lee et al. [1987]. Normal relative displacement over the fault plane, which tends to occur because of the free surface, is constrained to be zero. A fairly large set of forward searches was performed to find the model parameters that give a best fit to the observed coseismic geodetic data [Lisowski, personal communication, 1990] subject to the constraint that the fault geometry agrees roughly with the aftershock locations [Dietz and Ellsworth, 1990].

Reasonable agreement with the deformation data is obtained with a model for which subequal components of stress drop along strike and dip are applied over an oblique fault plane. Table 1 shows the fit of the best model to the geodetic data. For brevity, the data with magnitudes smaller than 35 mm are not shown. The mean misfit to all data is 40.8 mm, about 2.5 times the data error which is about 15 mm. The largest misfit occurs for the line lp1-lp2. As pointed out by Lisowski et al. [1990], it is likely that this line is affected by local movements, given the widespread surface cracking and secondary faulting observed in the epicentral area [U.S.G.S. Staff, 1990]. The strike, the inclination angle (downdip), the depth of the fault center, the fault length, and the fault width are about N48°W, 75°, 11.5 km, 50 km, and 17 km, respectively. The stress drop components determined by minimizing the difference between the observed and predicted surface deformation are $\Delta\tau_s$ = 1.2 MPa and $\Delta\tau_d$ = 1.5

MPa. The calculated geodetic moment is 2.5×10^{19} Nm. The maximum energy release rate (energy released per unit area of fault advance) occurs near the top of the fault and is estimated to be $5.5\times10^{6}J/m^{2}$. If it is assumed that the slip propagated according to the criterion that the energy release rate is equal to a critical value, then the estimated value is the critical energy release rate corresponding to arrest of the earthquake. The slip distribution over the fault surface is approximately elliptical. The average slips in the strike and (reverse) dip directions are $[\bar{u}_s]$ = 1.1 m and $[\bar{u}_d]$ = 0.9 m, respectively.

The geodetic moment, the dipping angle, and the ratio between strike and dip slip are very close to those (2.8×10^{19} Nm, 70°, and 1.3) of Lisowski et al. [1990]. The magnitudes of our strike and dip slip are smaller than theirs (1.6 m and 1.2 m) because our best model prefers a fault geometry having a larger area. If we use the geometry suggested by Lisowski et al., the mean misfit to data is increased to be 64 mm.

References

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Publication

Wu, M. and J. W. Rudnicki, Use of stress drop models to interpret geodetic measurements at Loma Prieta, California (Abstract), presented at Fall AGU Meeting, 1990.

Table 1. Model Fit to Geodetic Data

Station - Station		Observed (mm)	Calculated (mm)	Residual (mm)
Geodolite Line Length Changes				
allison	bmt rf	-39.2 ± 11.8	-25.1	-14.1
american	hamilton	75.0 ± 9.4	52.7	22.3
american	loma use	-66.5 ± 7.8	-32.8	-33.7
biel	eagle rk	101.5 ± 7.2	60.3	41.2
biel	loma use	235.4 ± 11.6	218.4	17.0
biel	mindego	-107.5 ± 8.8	-98.1	-9.4
bmt rf	loma use	176.2 ± 18.1	106.9	69.3
butano	dump	-39.7 ± 5.7	-32.3	-7.4
butano	eagle rk	-95.2 ± 5.5	-56.2	-39.0
butano	pom	-46.2 ± 11.1	-32.9	-13.3
gilroy	llagas	-48.5 ± 7.9	-50.8	2.3
hamil ec	llagas	37.3 ± 8.9	3.4	33.9
hamil ec	sheeprm2	-42.1 ± 12.7	-24.9	-17.2
llagas	lp1	-54.0 ± 6.0	5.0	-59.0
llagas	sheeprm2	74.3 ± 11.9	14.6	59.7
loma use	mindego	175.0 ± 12.8	122.9	52.1
allison	lomancer	109.0 ± 8.0	78.1	30.9
eagle rk	lomancer	259.7 ± 5.8	202.5	57.2
hamilton	lomancer	51.1 ± 6.0	52.6	-1.5
lomadwr	pr6	-274.1 ± 20.1	-236.9	-37.2
lp1	lp2	-40.9 ± 5.2	146.4	-187.3
lp1	lp4	-212.0 ± 7.9	-221.1	9.1
brush 2	fremont	-18.1 ± 10.0	-9.7	-8.4
brush 2	mulligan	49.4 ± 6.9	30.1	19.3
chamber	vargo	123.9 ± 7.2	127.9	-4.0
fremont	juan	42.5 ± 6.0	6.3	36.2
gilroy	juan	-63.4 ± 11.4	-33.8	-29.6
juan	mulligan	-36.8 ± 8.7	-13.2	-23.6
lp1	vargo	-204.0 ± 15.3	-239.0	35.0
fremont	sargent	54.2 ± 12.9	-15.6	69.8
canada	fairview	-39.3 ± 12.2	-8.0	-31.3
canada	sargent	-86.3 ± 25.0	-1.4	-84.9
fairview	gilroy	-68.2 ± 13.7	-19.3	-48.9
gilroy	sargent	-89.9 ± 12.6	-16.1	-73.8
gilroy	sheeprm2	-69.8 ± 11.1	-19.0	-50.8
canada	gilroy	-51.9 ± 7.5	-8.7	-43.2
p2	p3	44.6 ± 23.1	-5.5	50.1
p3	p4	66.6 ± 14.0	5.2	61.4
p3	p5	66.6 ± 23.1	11.3	55.3
p4	p5	46.0 ± 11.3	6.3	39.7

Table 1. (continued)

p5	p6	87.3 ± 13.7	-0.8	88.1
p5	p7	-43.3 ± 13.5	-9.6	-33.7
p7	p8	73.7 ± 10.6	8.0	65.7
p5	chamb 2	-41.8 ± 12.0	-7.3	-34.5
GPS East				
1p1	allison	34.8 ± 5.9	70.2	-35.4
1p1	eagle un	225.2 ± 11.8	243.6	-18.4
1p1	hamilton	65.6 ± 7.0	66.0	-0.4
1p1	brush 2	41.3 ± 15.6	78.4	-37.1
GPS North				
1p1	allison	-110.6 ± 3.8	-103.7	-6.9
1p1	eagle un	-205.4 ± 5.6	-145.3	-60.1
1p1	hamilton	-106.6 ± 2.6	-96.2	-10.4
1p1	brush 2	-229.2 ± 4.6	-205.1	-24.1
GPS Up				
1p1	allison	-105.5 ± 33.4	-139.1	33.6
1p1	eagle un	-211.8 ± 24.7	-202.6	-9.2
1p1	hamilton	-114.4 ± 25.5	-131.4	17.0
1p1	brush 2	-40.0 ± 27.8	-143.4	103.4

Total Mean Misfit --------- (rms) = 40.8 mm

Observed Changes are given with the conventions: Post-Seismic value -Preseismic value, and Station B - Station A.