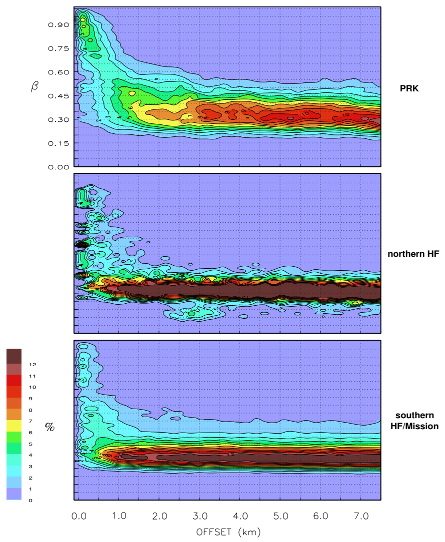

Figure 10.13: Cluster Signatures from NCSN waveform archives for earthquakes at Parkfield (PRK), the northern Hayward Fault (northern HF), and southern Hayward / Mission faults (southern HF/Mission). In this analysis, comparisons of waveform similarity between all possible pairs of earthquakes are made. The similarity of the earthquakes, as manifest in maximum waveform cross-correlations, are shown on the ordinate (β) axis and the distance between the two events is given on the abscissa. Contoured values show the relative number of event pairs with given similarity separated by a given distance. Hence spatial clusters of very similar earthquakes (including all repeating earthquakes) plot in the upper left hand quadrant, while less similar widely separated earthquake pairs plot in the lower right hand quadrant. Note that theoretically for completely uncorrelated waveforms, β should be equivalent to the maximum correlation of white noise (ie. 0.25).

revealed a systematic organization in space and time, dominated by clustering of nearly identical, regularly occurring microearthquakes ('characteristic events') on 10-20 m wide patches within the fault zone (Nadeau and McEvilly, 1997, 1999). At Parkfield, more than half of the 5000+ events in the 1987-1998 catalog exhibit this trait. In general, recurrence intervals (0.5 to 2 yr.) scale with the magnitude of the repeating events for the magnitude range available (M_w 0.2 to 1.3). Clusters of these characteristic events occur throughout the slipping fault surface. Scalar seismic moments were estimated for 53 of the repeating sequences and combined with equivalent estimates from 8 similar but larger event sequences from the Stone Canyon section of the fault and the main Parkfield M6 sequence. These estimates show that seismic moment is being released as a function of time in a very regular manner. Measurements of the moment release rate, combined with an assumed tectonic loading rate, lead to estimates of the seismic parameters source area, slip, and recurrence interval. Such parameters exhibit a systematic dependence upon source size over a range of 10^{10} in seismic moment which can be described by simple scaling relationships (Nadeau and Johnson, 1998). What emerges from this analysis of moment release rates is a quantitative description of an earthquake process that is controlled by small strong asperities that occupy less than 1% of the fault area. A 26-months period of greatly increased activity during the study interval (M4.2, 4.6, 4.7 and 5.0 events and their aftershocks) accompanied changes up to 50% in previously stable recurrence intervals. Langbein et al. (1998) report on evidence in deformation measurements for a slip rate increase in 1993 at Parkfield. Nadeau and McEvilly (1999) show that it is possible under reasonable assumptions to infer the spatial distribution of variations in slip-rate on the fault surface from the changes in recurrence intervals for the characteristic event sequences. The analysis requires an assumption of constant area for the repeating sources - one easily supported by the lack of any detectable change in the waveforms (over the 100 Hz bandwidth) associated with the change in recurrence interval.

7.4 Improving Inversion for Fault Slip

We model the measured displacement field with rectangular displacement discontinuities with uniform slip in an homogeneous elastic half-space. A number of modeling and inversion tools have been developed that will enhance our ability to model these new data [e.g., Murray et al., 1993, 1996; Burgmann et al., 1994; 1997]. The addition of subsurface slip constraints to the inversion is fundamental to this proposed study. Even with the InSAR-quality range-change data available crossing the Hayward fault, determination of the vertical extent (creep patch width) of the creeping zone is nearly impossible to recover if the locked zone is deeper than about 3 km. Slip distribution at depth is elusive, and asperities are cannot be imaged even near the surface, without subsurface slip information. The next M6.5+ event on the Hayward fault will likely nucleate typically near the lower bound of the seismogenic zone, a depth of 8-10 km, where resolution of the slip distribution from surface observations is very poor. Constraints from recurrence-determined slip rates at a few depth points offers promise for substantially sharpened resolution near the all-important base of the slipping zone. We are working to improve the slip inversion data set by adding to the growing InSAR data base a combination of microearthquake-determined slip rates throughout the fault zone and enhanced GPS coverage from a tight rotating deployment of single-frequency L1 receivers in the center of our study region.

7.5 The M_w 4.1 El Cerrito Earthquake

The largest local earthquake that occurred along the northern segment of the Hayward Fault during the past year was a M_w 4.1 event which occurred at 4:16 AM local time on December 4, 1998 at a depth of 6.8 km along the Hayward Fault approximately 6.3 km northwest of the Berkeley campus. This earthquake was recorded by all the northern Hayward Fault Network stations and by the Caltrans bridge borehole sites.

Ground motions recorded at BDSN stations in the vicinity of the northern Hayward Fault are shown in Figure 10.14. The relative ground velocity traces are ordered from top to bottom by epicentral distance. Note the variation in the seismic wavefield with distance, azimuth, and side of the Hayward Fault. The crustal structure across the northern Hayward Fault zone, in the vicinity of Berkeley, is rather complex with a lateral bedrock velocity contrast of approximately 30% across the fault zone with the SW side fast and also with an attenuation contrast across the fault zone with the NE side having higher attenuation as evidenced by the variability in the observed seismic ground motions shown in Figure 10.14. For example, the observed waveforms at BKS (6.8 km away on NE side) and at BRK (5.8 km away on SW side) show considerable variation in the high-frequency spectral content, in the low-frequency coda duration, and in the S-P interval (a 60% change for a 20% increase in distance. The observation that the first motions at BKS and BRK are both dilational is an indication, given the right-lateral strike-slip source mechanism and compressional quadrant path to BKS, that the initial P-wave recorded at BKS is laterally refracted along the fault zone.

Bedrock ground motions at seven locations along the Bay Bridge for the M_w 4.1 earthquake are shown in Figure 10.15. Note that the character and phasing of the ground motion varies considerably from east to west (top to bottom in Figure 10.15) as the wavefield propagates across San Francisco Bay. Knowledge of the bedrock ground motions is of paramount engineering importance for seismic design of the bridge.

7.6 References

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