Caltrans Procedures for Calculation of Fault Rupture Hazard

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The development of the hazard curve for fault offset follows simplified procedures described in Abrahamson (2008) with some enhancement on the calculation of the recurrence interval based on personal communication. The method relies on the assumption that the fault in question ruptures predominately within a narrow range of magnitudes, the center of this range being defined as the characteristic magnitude, M_c. A relation by Hanks and Bakun (2008) given in (A1) can be used to estimate the characteristic magnitude from fault dimensions.

$$M_w = \begin{cases} A < 537\ km^2 & LogA + 3.94 \\ A > 537\ km^2 & \frac{4}{3} LogA + 3.07 \end{cases} \tag{A1}$$

For application to faults with aseismic creep, such as the Hayward fault, a reduced fault area A', defined in (A2), is used to account for the reduced seismogenic area.

$$A' = A\ (1 - aseismic\ factor) \tag{A2}$$

As an example, for the Hayward fault an aseismic factor of 0.4 is used resulting in a characteristic magnitude of 7.0.

The recurrence interval, T_r, for a characteristic earthquake can be estimated as

$$T_r = \frac{M_0}{0.8\ \dot{M}_0} \tag{A3}$$

where the seismic moment is given by (A4), (Hanks and Kanamori, 1979) and moment rate is given by (A5).

$$M_0 = 10^{1.5\ M_w + 16.05} \tag{A4}$$

$$\dot{M}_0 = \mu\ A' \dot{D} \tag{A5}$$

In (A4), M_w represents the moment magnitude. In (A5), μ is the rigidity and is typically taken as 3×10^{11} dyne/cm^2. $\dot{D}$ is the fault slip rate. A' is the modified fault plane area as given in (A2).

The 0.8 in the denominator of (A3) is a combined adjustment factor that addresses (1) a presumption that approximately 5% of the seismic moment is expended in small, non-characteristic events, and (2) the seismic moment associated with a characteristic magnitude, M_c, at the center of a uniform distribution ranging from M_c-Δm to M_c+Δm,

Δm typically assumed to be about 0.2 magnitude units, will underestimate the seismic moment when averaged across the uniform distribution.

Fault rupture hazard is typically defined in terms of the rate of exceeding a particular fault displacement, *D*. As shown in (A6), the hazard value is calculated as the product of two terms. The first term is the rate at which characteristic events occur and is simply the inverse of the recurrence period calculated in (A3). The second term is the probability, *conditioned* on the occurrence of the characteristic event, that the fault displacement is larger than *D*.

$$\begin{pmatrix} Rate\ of\ fault \\ offset\ exceeding \\ displacement\ D \end{pmatrix} = \left(\frac{1}{T_r}\right) \begin{pmatrix} Probability\ of\ fault \\ offset\ exceeding \\ displacement\ D \\ given\ the\ occurrence\ a \\ characteristic\ EQ \end{pmatrix} \tag{A6}$$

This probability is represented by the hatched area in Figure A1. The curve describes the lognormal probability distribution of the fault displacement for the characteristic earthquake.

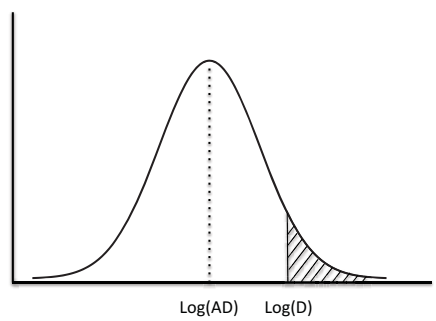

Figure A1: Lognormal probability distribution for fault displacement resulting from a characteristic earthquake.

The center of the distribution is the logarithm of the average displacement, AD, and is given by a relation by Wells and Coppersmith (199x) for strike slip faults.

$$Log(AD) = 0.9M_w\text{-}6.32 \quad \text{(meters)} \tag{A7}$$

The hatched area in Figure A1 can be calculated as

$$hatched\ area = 1 - \Phi(\varepsilon) \tag{A8}$$

where Φ represents the cumulative distribution function (CDF) of a standard normal variate (i.e. mean=0, standard deviation=1) and ϵ is given as

$$\varepsilon = \frac{Log(D) - Log(AD)}{\sigma} \tag{A9}$$

where σ is the standard deviation of the fault displacement (in log space) and is typically estimated as 0.39 unless fault offset measurements are available from previous events.

In application, an inverse CDF is used to determine the ε that corresponds to the desired rate of exceedence. (In Excel, the function NORMINV can be used to perform the inverse CDF calculation.) Once ε has been determined, the corresponding displacement D can be calculated as

$$D = AD\ 10^{\varepsilon\sigma} \tag{A10}$$

<u>Sample calculation</u>

For the Hayward fault we assume a fault plane of approximately 1400 km^2, a slip rate of 9 mm/yr, and an aseismic factor of 0.4. Calculate the displacement corresponding to a $^1/_{975\ yr}$ rate of exceedence:

Using (A2) we get

$$\begin{aligned} A' &= 1400\ km^2(1-0.4) \\ &= 840\ km^2 \end{aligned}$$

The corresponding magnitude is estimated using (A1):

$$\begin{aligned} M_w &= \frac{4}{3}Log(840) + 3.07 \\ &= 7.0 \end{aligned}$$

The recurrence period is calculated using (A3):

$$T_r = \frac{10^{1.5\ (7)+16.05}\ dyne - cm}{0.8\ (3x10^{11}\frac{dyne}{cm^2})(840\ km^2)(10^{10}\frac{cm^2}{km^2})(0.9\ \frac{cm}{yr})}$$

$$= 195\ yrs$$

Using (A6) and (A8), we determine that for our target $^1/_{975\ yr}$ rate of exceedence, the conditional rate of exceedence (which is represented by the hatched area in Fig. A1) is given by

$$\begin{aligned} hatched\ area = 1 - \Phi(\varepsilon) &= \frac{^1/_{975}}{^1/_{195}} \\ &= 0.2 \end{aligned}$$

Using an inverse CDF function we determine that 0.2 corresponds to an ε of 0.84. The mean fault offset, AD, corresponding to a M_w7 event is given by (A7):

$$\begin{aligned} AD &= 10^{0.9\ (7)-6.32}\ (meters) \\ &= 0.95\ m \end{aligned}$$

Finally, we calculate D using (A10):

$$D = (0.95m)10^{(0.84)(0.39)}$$

$$= 2\ m$$

This calculation is repeated for different rates of exceedence to establish the hazard curve.

References

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