SECOND-ROUND QUESTIONS

RELATED TO THE EPRI TOPICAL REPORT

prepared for the

Nuclear Regulatory Commission

by

U.S. Geological Survey

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Relation between earthquake size and attenuation

Q1. By what means is it assured that the conversions of intensity to magnitude are consistent with the magnitude units used in the attenuation functions? How are catalog magnitudes adjusted to correspond to the definitions of magnitude used by those who have derived the attenuation functions?

Effect of method of upper-bound truncation

Q2. The Weston team reports (page 6-10, 25–26, and table 6-2) that the truncation method "reaches down" to affect magnitude exceedance rates a magnitude unit below the truncation magnitude. What is the effect of adding 0.3 magnitude units to upper-bound magnitudes on the recurrence rates of ground motion values at 0.3, 0.5, and 0.7 g for b-values of -0.7, -0.9, and -1.1?

Tectonic features considered

Q3. We find that in the team reports, Bechtel states that they used a cut-off P_A of 0.05 for consideration of tectonic features. Law reports a cut-off of 0.25. Please furnish us with the cut-off P_A's of the other teams.

Grid limitations

Q4. What practical limitations (long computing time, high variability of cell a- and b-values, etc.) are there, if any, to using the methodology with cell sizes of 1/4 degree when cells are used to define seismic parameters?

Seismicity Parameters

Q5. We could not duplicate the a value in Table 4-4, Vol. 4, for source 16. Source 16 has 7 earthquakes; when 6 earthquakes are placed in the first magnitude interval (3.3-3.9) and 1 earthquake in the second (3.9-4.5), and the equivalent completeness time periods (table 4-3) for the Weichert algorithm are used, we obtain $b = -1.71$ as in Table 4-4, but a *different* a value.

(a) Does a in Table 4-4 represent the (log) number of earthquakes greater than magnitude 3.3, the (log) number of earthquakes in the range 3.3-3.9, or some

other number? (We are unable to find an interpretation for a that gives the EPRI result of $a = -1.47$.)

(b) Please show the a and b values calculated using your code for the Weichert algorithm for 81, 27, 9, 3 and 1 earthquakes in magnitude intervals 3.3-3.9, 3.9-4.5, 4.5-5.1, 5.1-5.7, 5.7-6.3 respectively, and 1 year observation time in each case.

(c) Please provide the EPRI code used for the Weichert algorithm to estimate a and b values for varying time periods of catalog completeness.

(d) Table 4-3 shows equivalent time period, which is said to be a product of total time and detection probability. If these numbers are used as completeness time in Weichert's method, rather than values for that much shorter time for which a homogeneous rate of low magnitude earthquakes is observed, the result is to weight quite highly numbers which are very unreliable (because the fraction of past small earthquakes that has been observed varies with time, and the determination of detection probability is problematic). Provide example comparisons of the application of EQPARAM and Weichert's method to earthquake observances over homogeneous time periods for the simulated catalog.

e) In Vol. 4, pp. 4.2ff., it is stated that an artificial catalog was generated to test EQPARAM. The tests showed EQPARAM compared well with other methods. It is not stated how EQPARAM b-values compared to the b-value assumed in the simulation. What b-value was used to generate the artificial catalog?

Q6. When no earthquakes have been observed in a cell, "in the final estimates of a and b, EQPARAM balances the expected number of earthquakes with the number of observed events" (Vol.4, page 4-5). It appears that almost any value of b may be obtained for a cell that started with no earthquakes, depending on the smoothing parameters and tolerance levels; e.g., for cell 30 (beginning with 0 earthquakes), various degrees of smoothing give b estimates that range from from $b = 0.92$ to $b = 3.62$. Please explain how the observed and expected numbers of events are balanced, and how the final a and b are obtained.

Q7. Vol.4, Section 4.2.1.2 (pages 4-5, 4-6) Re: consistency of different ways of using EQPARAM to calculate seismicity parameters. Why are not the results reported in

Table 4-6 for the two ways identical? Are not the calculations in the two cases exactly the same?

Q8. Vol.4, Table 4-7 shows estimates of a and b for various degrees of smoothing. If PENA=0 and PENB=0 represents no smoothing in a and b and PENA=PENB=5000 represents high smoothing in a and b, we would expect estimates of a and b for intermediate smoothings (e.g., 0 <PENA,PENB< 5000) to lie between the estimates obtained for the extreme cases, but this is not necessarily true. For example, for PENA=50, PENB=0, the estimates of b do not lie between the estimates obtained for the extreme cases. This is counterintuitive, and the large change in b from the case PENA=PENB=0 is particularly surprising because the smoothing on a is low, and there is no smoothing on b. Please explain how and why the calculation procedure gives this result, and why a counterintuitive result should be accepted.

Q9.

(a) It is assumed that a higher fraction of large magnitude earthquakes than of low magnitude earthquakes has been observed. The fraction is assumed to be 1.0 for the highest magnitude interval. The probability of detection for the remaining magnitude intervals can be smoothed. "As the smoothing on the probability of detection increases, the final estimates should converge to the fixed value of 1.0" (Vol.4, page 4-8). Usually high smoothing would be expected to give an average value, or produce a linear increase from a value near the bottom of the range to a value near the top of the range. Why, in this case, should high smoothing of the probability of detection increase the estimated probability of detection for all magnitude intervals to the extreme value of 1.0?

(b) The estimated probabilities of detection for "moderate smoothing" do not lie between those obtained for "weak smoothing" and "high smoothing" (Vol.4, Table 4-13, page 4-46). This seems counterintuitive. Please explain.

Q10. The statement is made (Vol.4, page 4-9): "As the cell sizes are reduced to extremely small dimensions, the number of cells with events in them, or with adequate data, will decrease." In the example (Vol.4, Table 4-1), several cells on the 1° grid contain only four earthquakes. Is four earthquakes adequate data for estimating a and b-values? What is the definition of adequate data?

Q11. Re: specification of tolerance values and maximum number of iterations (Vol.4, page 4-9). Table 4-17 shows results for various degrees of smoothing of a and b (indicated by the quantities PENA and PENB) for 6 tolerance levels for each case. For

PENA=1000 and PENB=0, depending on the tolerance levels, the solution ranges from $a = -1.20, b = 0.48$ to $a = -1.07, b = 1.69$, (a variation in b of a factor 3.5). Please show the progression of the a and b values from the values ($a = -1.19$, $b = 0.48$) for the tolerances in case 2 to the values ($a = 1.09, b = 1.39$) for the tolerances in case 4 in Table 4-17. (Please include for each iteration, the differences that correspond to the tolerances.) Why should we believe a solution is meaningful when it depends so strongly on the tolerance level selected?

Q12. A large number of iterations may be required before the solutions (a and b values) satisfy the specified tolerances (Vol.4, page 4-9). "Small tolerance values must be specified to estimate the seismicity parameters in order to obtain global convergence (i.e., to determine the global maximum of the likelihood function) for low smoothing values on the probability of detection. At the extreme, there may be no convergence when there is no smoothing on the probability of detection" (page 4-11).

(a) Why may smoothing on the probability of detection be required to achieve convergence? Usually, when parameters covary, reducing the number of parameters that must be estimated (e.g., holding the probability of detection fixed) makes estimates of the remaining parameters more stable.

(b) Why should small tolerance values guarantee global (as contrasted with local) convergence?

Q13. Estimates of a and b values for a cell are smoothed by adding "penalty" terms to the usual maximum likelihood equations. The smoothing involves weighting the a and b values in neighboring cells. Does the smoothing take into account the number of earthquakes in the various neighboring cells? For example, if cell X_1 has 100 earthquakes and an adjacent cell X_2 has 4 earthquakes, we would tend to place more weight on b_1, the estimate of b for cell X_1 than on b_2, the estimate of b for cell X_2 in a smoothing operation involving b_1 and b_2. Is this being done? If not, why not?

Q14. Why is $A(x)$, the area at location X (Vol.1, page 3-58), included in the term that is added when a prior value for b is assumed? We would expect the number of earthquakes in a cell to be relevant, but not the area of the cell.

Q15. Re: Elements of the interpolator matrix [H] (Vol.1, page 3-45). Is a cell a neighbor of itself? How is h_{xx} defined? Please give an example of the [H] matrix or I-[H] matrix for a 2x2 or a 3x3 region. We think the weights for row $[W]_x$ (equation 3-66) should sum to zero, but we cannot make them do so.

Q16. Very high smoothing on a, on b, or on a and b for each cell should give the same a, b, or (a,b) values that would be obtained if all the earthquakes in the entire region were grouped together and a single estimate of a, b, or (a,b) were made using all the earthquakes simultaneously. How sensitive are the results in each case to the selected tolerances? Why does smoothing on a (with PENB=0) alter the b-value for a cell?

Q17. The relationship given by equation (Vol.1) 3-39 is used in subsequent equations. Should this relationship not be $m(x)=\sum_m \sum_t m\ n(x,t,m)$?

Team Aggregation

Q18. Combining results for various teams.
The aggregation procedure apparently weights a team by how consistent its estimates are relative to other teams' estimates, and by covariances with other teams' estimates. For the Shearon Harris site, Team 1's estimates are dramatically lower than the other teams' results (Vol.4, Figure 6-2c). Team 1 is also appreciably lower at Braidwood (Figure 6-3c) and lowest at Millstone (Figure 6-7c). At five of the remaining sites it is one of the lower teams; at one site it is highest. Team 1 does not appear to be more consistent than other teams, (i.e., the large deviation for the Shearon Harris site alone would give it a large residual). How can Team 1 reasonably end up with about half the total weight?

Using Figures 6-2c, 6-3c, 6-4c, 6-5c, 6-6c, 6-7c, 6-9c, 6-10c. we have rank ordered the teams at the 6 sites for the fourth acceleration level: "1" means the team has the highest result among the six teams at a given site, etc; "6" means the team had the lowest result at a site. Figure 6-8c only shows 5 Teams, and is not included. (Please add the remaining team's results to Figure 6-8c.) The orderings may possibly contain errors because they were read from the figures, and the labeling was not clear in every case.

Team 1: 6,6,4,5,5,6,1,3
Team 2: 4,3,6,6,4,4,5,4
Team 3: 2,5,5,4,6,2,6,6
Team 4: 1,1,1,3,3,3,4,2
Team 5: 3,4,3,2,2,5,3,5
Team 6: 5,2,2,1,1,1,2,1

Team 5 is never extreme, yet it receives only 14 per cent of the weight for the fourth accleration level, while Team 1 receives 59 per cent. Team 3 receives only 1 per cent of the total weight; yet Team 3 appears similar to Team 1 in its behavior. How can these weights be justified, if a priori, all teams are regarded as competent? Also, it appears

that if a team is generally consistent with other teams, but radically different from the other teams at a single site, by this algorithm, the team will receive almost no weight at all sites. This seems to us like a rather severe penalty. Please comment.

Q19. Re: Vol.4, Table 6-12. At 0.05 g., Team 6 and Team 1 have similar deviations (0.115 and 0.106, respectively); yet Team 6 has a weight of 0.119 while Team 1 has a weight of 0.425. Also, Team 6 always has a lower deviation than Team 5, and also a lower weight than Team 5. We thought a lower deviation implied a higher weight. Please explain.

Q20. The following example illustrates our understanding of how EPRI calculates correlations used in determining relative weights of various teams. Is our understanding correct?

Six teams,A,B,C,D,E,F use yardsticks to measure lengths of 9 items. Teams A and B use the same yardstick, which happens to be 36.35 inches long (i.e., the yardstick purports to be 36.00 inches long, but is in error); teams C,D,E and F use yardsticks which are in the range 35.999 to 36.001 inches long. All teams make some random error in each measurement; Teams A and B will have systematically low readings, because of bias in their yardstick. All random errors are independent.

We believe that the EPRI approach would be to first determine 9 measurement errors for each team. If A_i is the measured value of object i by Team A, the "error" e_{A_i} of Team A at object i is the difference $e_{A_i} = A_i - \bar{m}_i(A)$ where $\bar{m}_i(A)$=(weighted) mean measured value of object i calculated using the 5 remaining teams (excluding team A). EPRI then would calculate an average error for each team, $\bar{e}_A = 1/9 \sum_{i=1}^{9} e_{A_i}$ and define correlations between teams as

$$\frac{\sum_{i=1}^{9}(e_{A_i} - \bar{e}_A)(e_{B_i} - \bar{e}_B)}{\sqrt{\sum(e_{A_i} - \bar{e}_A)^2 \sum(e_{B_i} - \bar{e}_B)^2}}.$$

Note that this procedure removes all systematic errors (e.g., the low readings for Teams A and B) and tries to find correlations between the random errors. This is unjustified. In this example, the only useful correlation results because the two teams that are systematically low (A and B) used the same biased yardstick. The fact that a pair of teams deviates systematically from the mean could be informative, but the EPRI procedure removes systematic deviations before checking for correlations, with the result that any apparent correlations between teams are spurious.

Measurement errors of Teams A and B will be positively correlated, if correlation is defined as

$$\frac{\sum_{i=1}^{9}(A_i - m_i)(B_i - m_i)}{\sqrt{\sum(A_i - m_i)^2 \sum(B_i - m_i)^2}}$$

m_i=mean measured value of object i,

$$m_i = 1/6(A_i + B_i + C_i + D_i + E_i + F_i).$$

Modifying the example, let us assume instead that Teams A and B each have 2 biased yardsticks available. A yardstick is selected (possibly at random) to measure each object; both A and B use the same yardstick to measure a given object. (This might correspond to different treatments of zones with low and high seismicity, etc.) By EPRI's definition of correlation, whether A and B are correlated again depends on the happenstance of random errors. It appears that EPRI is removing useful information in its weighting procedure and trying to read meaning into the noise. Please comment.

Could EPRI show "aggregate team weights and systematic deviations" (similar to Vol.4, Table 6-12) determined for each team without removing the individual team means (i.e., team systematic bias) in computing the variance and covariance matrix?

Q21. It seems reasonable to expect that one team's methodology might be best for high-seismicity sites, while another team's methodology is best for low-seismicity sites. The EPRI aggregation procedure results in one team receiving the highest weight for all sites. By a simple analysis we performed (based on crude covariance and correlation matrices using simple measures of deviation from median estimates for each site), we found Team 5 should have the highest weight if all sites are considered simultaneously. However, when sites are ranked by median exceedance rates at the highest ground motion value, we concluded Team 5 should receive the highest weight for only the 4 (or 5) lowest rate sites. Team 4 should receive the highest weight for the 5 highest-rate sites. By dividing the sites in this manner please report the weights obtained in each case under the EPRI aggregation methodology.

Q22. The technique used by EPRI to weight team estimates is referred to as Method 4 or EQAG; it makes use of correlations of random errors between teams, as discussed in the preceding questions. It is compared with several other methods for combining team estimates. "On the average... the standard error of estimation for Methods 2 and 4 are high relative to Method 3.." (Vol.4, pages 4-23, 4-24). "In comparison to other methods (e.g., equal weighting of teams) EQAG (Method 4) has favorable properties in the sense that the bias and variability of the estimator of the MLH is lower than other methods that were examined" (page 4-24). Explain how the two statements are consistent.

When the full covariance matrix is used to generate random correlated MLH values for each team at each site, "in general the mean estimates of the team weights for Methods

2, 3, and 4 deviate considerably from the true weights. In addition, the standard error of estimation of the team weight estimates is high for Methods 2 and 4 relative to the mean value (e.g., coefficients of variation 50 to 100 percent)" (Vol.4, page 4-22).

(a) Despite the previous observations, does EPRI conclude from simulations that Method 4 is, nevertheless, to be preferred to other methods?

(b) In the covariance matrix used in the EQAG simulation (Vol. 4, Table 4-33), Cov(1,2) = -Cov(2,1) and Cov(2,4)=-Cov(4,2). Are these numbers misprints, do they result from programming errors, or is there some other explanation?

Q23. Do the fractiles obtained using equal team weights (Figures 6-2a, 6-3a,...6-10a) include variability of each individual team's results, or are these fractiles based on median estimates for each team? (If variability is included, how is this done?) If unequal weights for each team are used to obtain an average of the median values, would it not be more consistent to calculate the .15 and .85 fractiles using unequal weights?

Magnitude Conversions and Rates

Reference: Appendix A (April 30, 1985)

Q24. To obtain m_b^* (the uniform magnitude or magnitude that has the same rate as the rate of earthquakes observed at m_b), when m_b is determined directly from instrumental data, m_b^* is given by

$$m_b^* = m_b - \frac{b\sigma_{mb}^2}{2},$$

and when $\hat{m}_b$ is obtained by conversion from another magnitude scale X, for an observed $\hat{X}$,

$$m_b^* = m_b(\hat{X}) + \frac{b\mathrm{Var}[m_b|\hat{X}]}{2}.$$

(a) These corrections to obtain m_b^* are based on the assumption of a doubly infinite magnitude range; the corrections are not valid for low magnitudes (where not all earthquakes have been recorded) and for magnitudes near the maximum magnitude in a finite range. Please discuss the justification for using the corrections throughout the magnitude range, when magnitudes are restricted to a finite range.

(b) The variance $\mathrm{Var}[m_b|\hat{X}]$ that is used in the corrections when magnitudes are converted from scale X to m_b (using the fitted relationship $\hat{m}_b = \alpha + \beta X$) is given by

equation A-65, Appendix A, and includes variability that results because of uncertainty in estimates of the coefficients α and β. Assuming a doubly infinite magnitude range, as does the EPRI analysis, why does EPRI include all possible error terms in the "correction" rather than just the observational error in X?

Q25. The EPRI analysis is based on a continuous distribution of both m_b and X. When $X = I_0$ (epicentral intensity), X is defined only at a set of integers, and a range of magnitudes corresponds to a single intensity value. How does EPRI justify using the results of an analysis based on a continuous distribution of magnitudes and infinite magnitude range for a discrete distribution and a finite magnitude range?

Q26. Magnitude intervals $\Delta m = 0.6$. are used in some of the examples (e.g., Vol.4, Table 4-19) with limits 3.3-3.9, 3.9-4.5, 4.5-5.1, 5.1-5.7, etc. An example in Appendix A, page A-70, gives for an $I_0 = 7$ earthquake, the values $m_b = 5.0$ and $m_b^* = 5.4$. Does this imply that the magnitude intervals selected for the analysis are such that the m_b^* values converted from intensities are at the centers of the intervals? On the other hand, equation A-1 (Appendix A) seeks the rate of earthquakes with body-wave magnitude between m and $m + dm$. For consistency with $\hat{m}_b^*$ values converted from other scales and consistency with the above equation, should not m_b^* be at the lower end of the magnitude interval corresponding to the given intensity?

Q27. Re: Fitting by doing a locally weighted linear least- squares fit.

(a) Weighting the observations as in equation A-13 means that the fitted line will match the data more exactly in the vicinity of x, and estimates of the slope will reflect the slope in the vicinity of x. If the slope changes with x, obviously the relationship between m_b and x is not linear for the range of x. If $X = I_0$, some intensities could correspond to a larger range of magnitudes than do other intensities. How would EPRI determine the magnitude range for each intensity in this case?

(b) The various procedures for determining a and b values (e.g. the Weichert algorithm) assume evenly spaced magnitude intervals (e.g., $\Delta m = 0.6$). If some intensities correspond to a wider range of magnitudes than other intensities, when intensities are converted to magnitudes, a single magnitude interval might contain magnitudes converted from two intensities and another magnitude interval might contain no converted magnitudes. How does EPRI deal with this?

Q28. Assume earthquakes that have been converted to m_b from various magnitude scales are grouped together at even intervals in m_b (e.g. $\Delta m_b = 0.6$ units). Are now

all earthquakes in a given magnitude interval weighted equally in estimating a and b values? (e.g., are $\hat{m}_b$ values that have been converted from I_0 values distinguishable from the directly recorded m_b values in the subsequent analysis?) Does EPRI take into account the fact that magnitudes of some earthquakes are better known than magnitudes of other earthquakes when estimating a and b values? If so, please explain in detail the algorithm used to determine a and b.

Q29. In fitting a and b values for a cell, each team is permitted to assign weights to earthquakes in each magnitude interval. How does this weighting interact with the weightings based on estimates of probability of detection for each cell?

Q30. "As an alternative to using the uniform magnitude, the maximum likelihood method for the estimation of seismicity parameters has been extended to explicitly deal with uncertainty on m_b....Because the posterior distribution depends on the recurrence rate, which is initially unknown, counting of the earthquakes is in this case repeated each time a new set of $a(x)$ and $b(x)$ extimates are found" (Vol.1, page 3-47). (Here x refers to a cell; $a(x)$ and $b(x)$ are estimates of a and b for cell x). The magnitude correction term depends on $b(x)$, and when $b(x)$ changes, a given earthquake may be assigned to a new magnitude interval.

Corrections for $\hat{m}_b$ values converted from intensities, for example, assume that the coefficient $\hat{\alpha}$ in the fitted relationship $\hat{m}_b = \hat{\alpha} + \hat{\beta} I_0$ is biased because of observational errors in I_0 and because of the negative exponential distribution of magnitudes (the b value). The bias in $\hat{\alpha}$ depends on the b value for the set of (m_b, I_0) pairs used in determining $\hat{\alpha}$ and $\hat{\beta}$.

(a) Are individual $b(x)$ values being estimated for subsets of the same set of earthquakes that was used to estimate the coefficients $\hat{\alpha}$ and $\hat{\beta}$?

(b) Should not any "corrections" based on individual $b(x)$ values also take into account the bias in $\hat{\alpha}$ resulting from the b-value in the set of earthquakes used to fit $\hat{\alpha}$ (i.e., if b for the entire set of earthquakes is different from the local $b(x)$, should not a correction into account the difference in b-values)?

(c) If earthquakes are selectively missing at some magnitudes, the fitted relationship $\hat{m}_b = \hat{\alpha}_i + \hat{\beta}_i X_i$ fitted to pairs (m_b, X_i) will not have the assumed bias. Does EPRI consider this in correcting m_b values to obtain m_b^*?

(d) The EPRI corrections based on a bias in $\hat{\alpha}$ implicitly assume a constant b value for all earthquakes in the set used to estimate $\hat{\alpha}$. The bias term will

be considerably more complicated if earthquakes in areas with differing b values are combined to estimate $\hat{\alpha}$. Does the EPRI treatment not contain inconsistencies in assumptions from one part of the analysis to the next?

Q31. Discussions in Appendix A (e.g, Sections A-1 and A-2) concern inverting the relationship $X_i = \alpha_i + \beta_i m_b$ to obtain m_b as a function of X_i. In practice, is the relationship $\hat{X}_i = \hat{\alpha}_i + \hat{\beta}_i m_b$ actually "inverted" to obtain $\hat{m}_b$ as a function of $\hat{X}_i$?