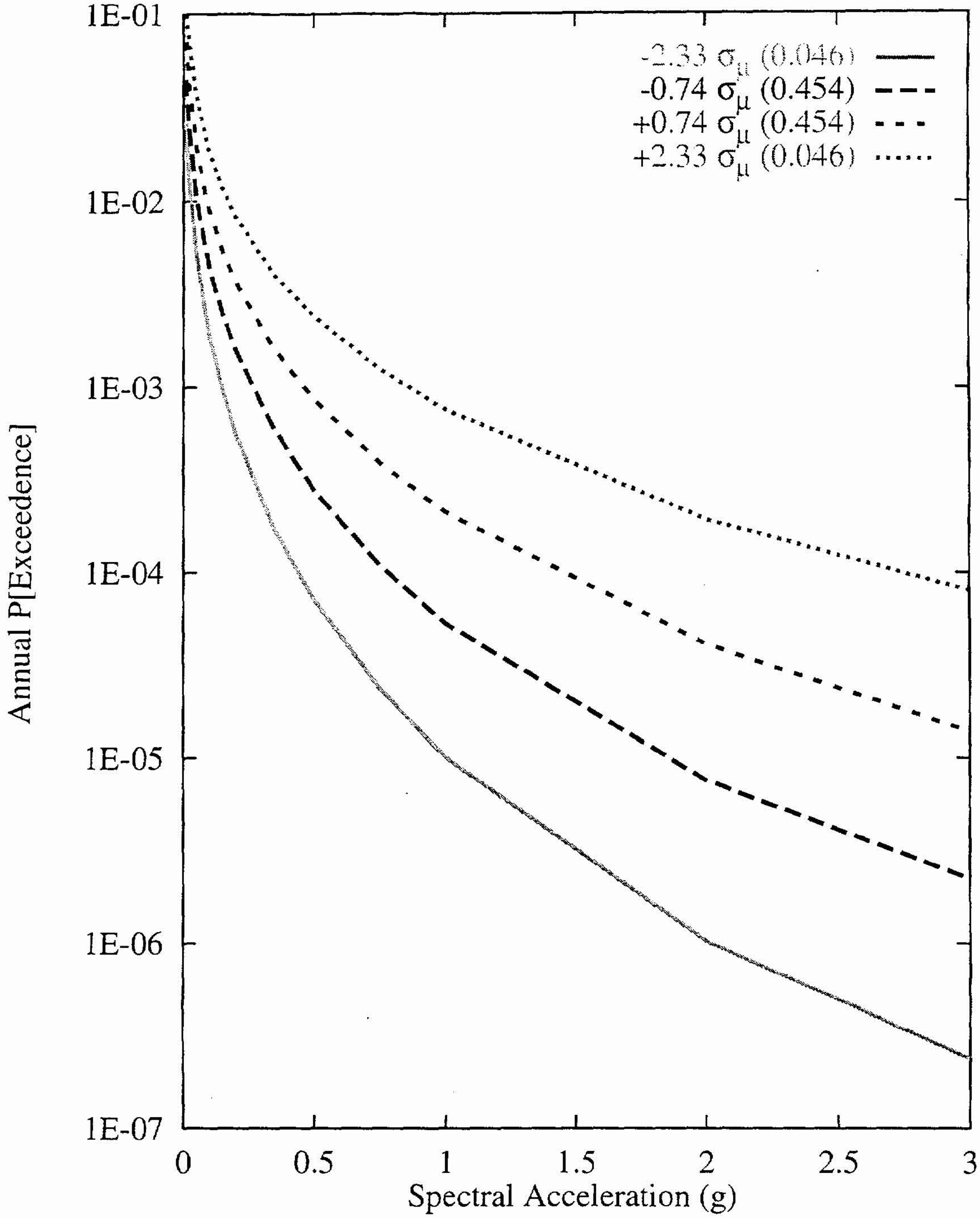

Figure 7-187 Sensitivity of seismic hazard to within-expert epistemic uncertainty in the median ground motion amplitude: ASM team, 10-Hz vertical spectral acceleration

8.0
PSHA METHODOLOGY AND RESULTS FOR FAULT DISPLACEMENT HAZARD

This section describes the methodology used to perform the probabilistic seismic hazard calculations for fault displacement at the Yucca Mountain site and the application of this methodology to nine points (referred to as "sites" in this chapter) within the Controlled Area. Section 8.1 introduces the PSHA methodology for assessing fault displacement hazard. This presentation uses many of the elements and concepts from the ground motion PSHA, which were introduced and described in Chapter 7.0. Section 8.2 presents the results for all nine demonstration sites, including sensitivity analyses.

8.1 PSHA METHODOLOGY FOR FAULT DISPLACEMENT

Fault displacement PSHA results in the probability that the tectonically induced fault displacement at a given site will exceed any value. The site of interest may or may not be on an active fault. Results are in the form of fault displacement hazard curves, which show annual exceedence probability for values of the displacement.

Of the two approaches for fault displacement PSHA described in Section 4.2, the earthquake approach calculates the principal and distributed faulting separately, using different attenuation equations, and then adds them to obtain a total displacement hazard curve. The displacement approach, on the other hand, considers both principal and distributed faulting but does not distinguish between them.

8.1.1 Earthquake Approach

The earthquake approach explicitly considers earthquake magnitudes and locations as intermediate variables in the calculation of fault displacement and uses the same seismic source models (i.e., source geometries and magnitude-recurrence models, and their associated uncertainties) that are used in the ground motion PSHA. The only substantive difference between the earthquake approach for fault displacement PSHA and the ground motion analysis described in Section 7.0 relates to the attenuation equations. These differences fall into the following two categories:

1. Because both principal and distributed faulting are non-uniformly distributed, there is a probability of no displacement at the site under consideration, given the occurrence of an earthquake in the vicinity of the site. Thus, the attenuation equation is written as the product of two terms: (1) the probability of nonzero displacement given the occurrence of an earthquake of certain characteristics at a given location and (2) the probability that the displacement at the site will exceed a value d*, given non-zero displacement.

2. Both the probability of nonzero displacement and the conditional probability on the amount of displacement depend on a number of quantities besides magnitude and distance. These quantities may be grouped into three categories: (1) geometry of the site relative to the rupture (particularly the along-rupture location x/L defined in Figure 8-1), (2) characteristics of the principal fault (e.g., total length, cumulative displacement), and (3) characteristics of the feature where the site is located (e.g., total length, cumulative displacement).

The resulting attenuation equations for fault displacement are of the form

$$G_D\left(d^* \middle| M, \underline{R}, \underline{X}_{principal}, \underline{X}_{site}\right) = P[D > O \mid M, \underline{R}, \underline{X}_{principal}, \underline{X}_{site}] \times P\left[D > d^* \middle| D > O, M, \underline{R}, \underline{X}_{principal}, \underline{X}_{site}\right] \quad (8\text{-}1)$$

where $\underline{R}$ represents the location of the rupture relative to the site (not just distance), and $\underline{X}_{principal}$ and $\underline{X}_{site}$ represent characteristics of the principal fault and site (all quantities in $\underline{X}_{principal}$ and $\underline{X}_{site}$ will be represented by $\underline{X}$ for the sake of brevity). Separate attenuation equations are developed for principal and distributed faulting. The attenuation equation for principal faulting is used only in conjunction with the fault where the site is located, if that fault is active. The attenuation equation for distributed faulting is used for all other faults and for the areal source zone containing the site.

The calculation of fault displacement hazard, considering all seismic sources and all earthquake magnitudes, is performed using a modified version of Equation 7-1, namely

$$v(d^*) = \sum_{i} v_i \iint_{\underline{r}\,m} G_D(d^* | m, \underline{r}, \underline{X}) f_{M(i)}(m) f_{\underline{R}(i)|M(i)}(\underline{r}; m)\, dm\, d\underline{r} \tag{8-2}$$

where i indicates source number, v_i is the rate of earthquakes on source i, $f_{M(i)}(m)$ is the probability density function of magnitude, and $f_{\underline{R}(i)|M(i)}(\underline{r}; m)$ is the probability density function of earthquake location (given magnitude). The calculation of fault displacement hazard given by the equation above is performed for multiple values of d^*. The result is a hazard curve, which gives the annual probability of exceedance as a function of d^*.

As in the case of ground motions, the primary interest is focused on computing probabilities for large but rare displacements. As a result, the probability of two or more events with $D > d^*$ in one year is negligible. Thus, the quantity on the right side of Equation 8-2, which is the annual rate of earthquakes with displacement $D > d^*$ is a very good approximation to the probability of exceeding displacement d^* in one year. If the quantity of interest is the maximum single-event fault displacement during a long time period T, one can use the equation $P[D_{\max}(T) > d^*] = 1 - \exp[-v(d^*)T]$. It should be emphasized that these hazard results are applicable to single events. If the quantity of interest is the cumulative displacement from one or more earthquakes over a long time period, which is not the intent in this study, it is necessary to use the theory of compound Poisson processes (Parzen, 1962).

8.1.2 Displacement Approach

The displacement approach uses a direct characterization of the occurrence rate of displacement events at the site and the probability distribution of displacement per event, without using earthquake magnitude and location as intermediate variables. The occurrence rate information may be provided as direct values of the rate λ or in the form of a slip rate SR. Specification of the probability distribution of displacement per event $P[D > d^* | \text{event}]$ is in the form of a scale parameter (such as the average displacement per event $\overline{D}_E$, maximum displacement D_{max}, or cumulative displacement D_{cum}) and information about the shape and spread of the distribution.

Calculation of the fault displacement hazard curve for the displacement approach (under the assumption of rare events discussed above) is straightforward, namely:

$$v(d^*) = \lambda \; P[D > d^* | event] \tag{8-3}$$

8.1.3 Treatment of Uncertainty

As with the ground motion PSHA methodology (discussed in Section 7.1), the formulations given above for the earthquake and displacement approaches for the fault displacement PSHA represent the aleatory uncertainty in the natural phenomena of tectonically-induced fault displacement. Mathematically, aleatory uncertainty is represented by the rates and probability distributions in Equations 8-1, 8-2, and 8-3. Epistemic uncertainty is associated with imperfect knowledge about these phenomena. In the earthquake approach, epistemic uncertainty is in the seismic source characterization, the attenuation equations, and the characteristics of the site that affect fault displacement. In the displacement approach, epistemic uncertainty is in the two elements of the model, namely the rate information and the parameters of the displacement per event distribution, as well as in the characteristics of the site that affect fault displacement.

Epistemic uncertainties in seismic source characterization and fault displacement attenuation equations are quantified by considering inputs from the six SSFD expert teams, and by each team's own assessment of epistemic uncertainty. Each expert team selects an approach for fault displacement PSHA (earthquake, displacement, or a weighted combination of both), and then formulates multiple alternative interpretations for the fault displacement attenuation equations (if using the earthquake approach) or for the rate and the distribution of displacement per event (if using the displacement approach). Calculations for the earthquake approach consider each expert team's fault displacement attenuation equations in conjunction with that team's source characterization.

Further details on the fault displacement models developed by the six SSFD expert teams are provided in Sections 4.2 and 4.3.2 and in the expert summaries(Appendix E).

8.1.4 Implementation of Methodology for Fault-Displacement PSHA

In the following, the earthquake and displacement approaches are discussed in the context of the implementation of the PSHA methodology.

8.1.4.1 Earthquake Approach. Calculations for the earthquake approach consider all local faults, as well as the host area source zone(s). The regional faults do not contribute to distributed fault displacement because the distributed displacement attenuation equations decay rapidly with distance, given the models formulated by the SSFD expert teams.

The rate portion of the attenuation equations for principal displacement (i.e., the first term in Equation 8-1) consists of a portion that depends on *x/L* (i.e., unity for *x/L* in the interval [0,1], zero otherwise), and a magnitude-dependent portion. The magnitude-dependent portion is a logistic function of magnitude, except for one team that considers the probability distribution of hypocentral depth, the magnitude-dependent rupture width, and the down-dip geometry of the fault. The rate portion of the attenuation equations for fault displacement is a logistic function of magnitude and distance, or peak ground velocity at the site. The rate portion for distributed faulting also includes the probability P[C] that the site is capable of fault displacement. This probability represents epistemic uncertainty (unless it is exactly zero or unity).

The distribution portion of the attenuation equations for principal and distributed displacement (i.e., the second term in Equation 8-1) is specified as an expression for the scale parameter of the distribution (e.g., mean displacement given magnitude, *x/L*, etc.), and information about the shape and spread of the distribution. For several teams, this expression consists of a product of several random terms. For instance, several teams calculate the principal displacement as the product of the maximum displacement, MD (taken as lognormal, with a median value that depends on magnitude) times a random shape function (which, for a given x/L, takes the form of a beta distribution with parameters that depend on x/L). In all these instances, these products are approximated using lognormal probability distributions, with medians and coefficients of variation computed using the well-known approximations for products of random variables. The accuracy of all these approximations was tested by comparing the exact and approximate distribution shapes.

There are also situations in which the distribution portion of the attenuation equation for distributed displacement is not a function of the earthquake magnitude or distance, and depends only on some characteristic of the site. This approach constitutes a hybrid between the earthquake and displacement method, where the occurrence portion of the model considers earthquakes, but the distance-distribution portion depends only on the characteristics of the site.

8.1.4.2 Displacement Approach. Although calculation of the hazard curve for this approach does not require integration over magnitudes and distances or summation over seismic sources, a logic tree analysis is required because the expert teams specified multiple alternatives for the various elements of the model and for the characteristics of the site.

8.1.4.3 Models Selected by the SSFD Expert Teams. Each team had the option of using the earthquake approach (chosen by one team), the displacement approach (two teams), and a weighted combination of the two approaches (three teams). The details on each team's approaches are described in Section 4.3.2 and their expert summaries (Appendix E).

8.2 PSHA RESULTS FOR FAULT DISPLACEMENT

The following describes the probabilistic fault displacement hazard calculated at the nine demonstration sites described in Section 4.3.2 and shown in Figure 4-9. Two of the sites have four hypothetical conditions representative of the features encountered within the ESF.

8.2.1 Integrated Results

The integrated results provide a representation of fault displacement hazard and its uncertainty at the nine demonstration sites, based on the interpretations and parameters developed by the six SSFD expert teams. Separate results are obtained for each site in the form of summary hazard curves, which are shown on Figures 8-2 through 8-14. No results are shown for Sites 7d and 8d because all summary curves for these sites are below an annual exceedance probability of 10^{-8}. Table 8-1 summarizes the mean displacement hazard results for the two annual exceedance probabilities of interest, 10^{-4} and 10^{-5}, at the nine demonstration sites.

With the exception of the block-bounding Bow Ridge and Solitario Canyon faults at 10^{-5} annual exceedance probability, the mean displacements are all less than 0.1 cm. At 10^{-5} probability, the mean displacements are 7.8 and 32 cm, respectively for the two faults (Table 8-1). Thus sites not located on the block-bounding faults such as sites on the intrablock faults, small faults, shear fractures, and intact rock are estimated to undergo displacements of significantly less than 0.1 cm for periods up to 100,000 years.

The mean and median hazard curves indicate the central tendency of the calculated exceedence probabilities. The separation between the 15th- and 85th-percentile curves conveys the effect of epistemic uncertainty on the calculated exceedance probability (note that for some sites the 15th percentile hazard curve, and sometimes the median hazard curve, does not appear on the figure because the entire curve is below 10^{-8} annual exceedance probability). This epistemic uncertainty includes team-to-team, as well as within-team epistemic uncertainty in both the fault displacement models and the source and site characterizations.

The epistemic uncertainty (measured by the distance between the 15th and 85th percentile curves), is higher for sites with no principal faulting, especially for those with the lowest cumulative displacements. Larger epistemic uncertainty at low hazard sites compared to high hazard sites is a common observation when comparing ground motion hazard PSHAs.

In some instances, the mean hazard curve is higher than the 85th percentile hazard curve. This is an indication that the mean hazard is being controlled by an interpretation that has a low weight, but predicts much higher hazard than the majority of the interpretations.

Some of the hazard curves also have a nearly flat portion for low displacements. For instance, Figure 8-3 is nearly flat between 0.1 and 10 cm. This implies that, if there is a displacement event on Solitario Canyon fault, it is likely to cause a displacement greater than 10 cm.

8.2.2 Comparisons Across Teams

Figures 8-15 through 8-27 show the mean hazard by each team, for all sites except 7d and 8d. Two mean curves are shown for those teams that used two approaches. For Sites 7b, 7c, 8b, and 8c, some teams specified *P[C]*=0, which implies that the hazard is zero. Although these curves are not shown on the figures, they are considered in the calculation of the summary statistics for the site.

Figures 8-15 through 8-27 indicate that variation among the SSFD expert teams is a significant contributor to total uncertainty. Recalling that the differences among the seismic source characterizations by the expert teams were small contributors to uncertainty in the ground motion hazard (Section 7.4.3), we can infer that the large differences among teams seen here are due to differences in the fault displacement models.

8.2.3 Sensitivity Results for Each SSFD Expert Team's Interpretations

Sensitivity results provide insights into the effect of various interpretations and parameters on the calculated seismic hazard and its uncertainty. These results provide insight into the PSHA process. They also provide a consistency check for the experts and analysts.

Sensitivity results are shown for Sites 1 (subject to both principal and distributed faulting) and 7a (subject to distributed faulting only). Several types of results are presented here for each combination of SSFD expert team and approach (earthquake versus fault displacement):

1. Summary hazard curves for that team's approach combination

2. Dominant seismic sources (for the earthquake approach only)

3. Sensitivity to important parameters of the fault displacement attenuation equations (earthquake approach) or to important parameters of the displacement model (displacement approach).

The procedure to generate the sensitivity results is described in Section 7.3.2.

8.2.3.1 AAR Team's Earthquake Approach. Figures 8-28 through 8-31 show the summary hazard curves and dominant seismic sources for Sites 1 and 7a. The most important contributors to hazard at Site 1 are the East-side coalesced system and Areal Source 2 (both contributors to distributed faulting), and the Bow Ridge fault (principal). The most important contributors to hazard at Site 7a are the East-side coalesced system and Areal Source 2.

For Site 1, the alternative displacement attenuation functions have small contributions to epistemic uncertainty. Most of the uncertainty at Site 1 is due to source characterization parameters (not shown), particularly the recurrence parameters for the dominant sources. For Site 7a, parameter beta, which controls the ratio of maximum displacement at the site to maximum displacement on the principal fault, is an important contributor to epistemic uncertainty (Figure 8-32). The AAR earthquake approach for distributed faulting is an example of the hybrid earthquake-displacement approach mentioned earlier. Because the shape of the attenuation equations does not depend on magnitude or distance, the mean hazard curves from all sources have the same shape.

AAR Team's Displacement Approach. Figures 8-33 and 8-34 show the summary hazard curves for Sites 1 and 7a. The hazard curves for the latter site shows a much more rapid drop-off and a slightly higher uncertainty. For Site 1, the most important contributors to uncertainty in the hazard are the cumulative displacement and the slip rate (Figures 8-36 and 8-37). For Site 7a, the most important contributor to uncertainty is parameter beta, which controls the ratio of maximum displacement at the site to maximum displacement on the principal fault (Figure 8-37).

8.2.3.2 ASM Team's Earthquake Approach. Figures 8-38 through 8-41 show the summary hazard curves and dominant seismic sources for Sites 1 and 7a. (The contributions by source on these figures are those obtained using the Borah-Peak reduction factor [70% weight] (Section 4.3.2.1), not the actual mean contributions.) The results for Site 7a show the effect of truncation at D_{cum}=2 m (Section 4.3.2.1). The most important contributors to hazard at Site 1 are the Stagecoach Road-Paintbrush Canyon (distributed) and Bow Ridge (principal) faults. The most important contributors to hazard at Site 7a are the Solitario Canyon and Stagecoach Road-Paintbrush Canyon faults.

For Site 1, the alternative displacement attenuation functions have small contributions to epistemic uncertainty. Most of the uncertainty at Site 1 is due to source-characterization parameters (not shown), particularly the recurrence parameters for the dominant sources. For Site 7a, the only important uncertainty in the displacement attenuation equations is the model used to scale displacement on the principal fault to distributed displacement at the site (Figure 8-42).

8.2.3.3 DFS Team's Displacement Approach. Figures 8-43 and 8-44 show the summary hazard curves for Sites 1 and 7a. For Site 1, the most important contributors to uncertainty in the hazard are the choice to use the recurrence interval or the average displacement per event $\overline{D}_E$ (both derived from paleoseismic observations; Figure 8-45), the value of $\overline{D}_E$ (Figure 8-46), and the value of the recurrence interval (Figure 8-47). For Site 7a, the most important contributors to uncertainty in the hazard are the capability for fault displacement at the site (Figure 8-48), the value of $\overline{D}_E$ (Figure 8-49), and the value of the recurrence interval (Figure 8-50).

8.2.3.4 RYA Team's Displacement Approach. Figures 8-51 and 8-52 show the summary hazard curves for Sites 1 and 7a. For Site 1, the most important contributors to uncertainty in the hazard are the recurrence interval (Figure 8-53) and the distribution shape (Figure 8-54). For Site 7a, the most important contributors to uncertainty in the hazard are parameter beta (discussed above for AAR and ASM; Figure 8-55), and the expression used in the calculation of slip rates from cumulative displacements (Figure 8-56).

8.2.3.5 SBK Team's Earthquake Approach. Figures 8-57 through 8-60 show the summary hazard curves and dominant seismic sources for Sites 1 and 7a.. The most important contributors to hazard at Site 1 are the Stagecoach Road-Paintbrush Canyon fault and the Basin and Range source zone (both distributed) and the Bow Ridge fault (principal). The most important contributors to hazard at Site 7a are the Basin and Range source zone and the Stagecoach Road-Paintbrush Canyon and Solitario Canyon faults.

For both Sites 1 and 7a, the alternative displacement attenuation functions have small contributions to epistemic uncertainty. The most important among these is the model for the probability of displacement given an event (not shown), for which SBK uses two models. The first model is a logistic function in terms of magnitude and distance. The second model is a logistic function in terms of the peak ground velocity predicted by the ground motion models. Although the latter model predicts higher hazard, its contribution to epistemic uncertainty is small because it has a weight of only 10%.

SBK Team's Displacement Approach. Figures 8-61 through 8-62 show the summary hazard curves for Sites 1 and 7a. For Site 1, the most important contributors to uncertainty in the hazard are the average displacement per event (Figure 8-63) and the recurrence interval (Figure 8-64). Site 7a has no important contributors to uncertainty in the hazard, as indicated by the tight clustering of the fractile hazard curves on Figure 8-62.

8.2.3.6 SDO Team's Earthquake Approach. Figures 8-65 through 8-68 show the summary hazard curves and dominant seismic sources for Sites 1 and 7a. For both Sites 1 and 7a, the alternative displacement attenuation functions have small contributions to epistemic uncertainty. Source characteristics also have a small contribution to epistemic uncertainty, as indicated by the tight clustering of the fractile hazard curves on Figures 8-65 and 8-66.

SDO Team's Displacement Approach. Figure 8-69 shows the summary hazard curves for Site 7a (no results are shown for Site 1 because SDO does not apply the displacement approach to sites with principal faulting). The most important contributors to uncertainty in the hazard are the ratio beta (Figure 8-70), the procedure to calculate the average displacement per event (Figure 8-71; SDO uses the procedures formulated by the AAR and SBK teams), and the procedure to calculate slip rate from cumulative displacement (Figure 8-72).

8.3 SUMMARY

The results shown here illustrate the wide diversity in approaches used to evaluate fault displacement hazard (Section 4.3.2.1). This diversity is indicative of the state of practice in PSHA for fault displacement, which is less mature than PSHA for ground motions. Nonetheless, the results obtained here are considered robust by virtue of the extensive efforts at expert elicitation and feedback, as well as the methodological developments, that were undertaken as part of this study. In addition, much of the experience in ground motion PSHA can be transferred into fault displacement PSHA. Sites with the highest fault displacement hazard show uncertainties comparable to those obtained in ground motion PSHA. Sites with low hazard show much higher uncertainties.

There is also an interesting, but not unexpected, correlation between the amount of geologic data available at a site and the uncertainty in the calculated hazard at that site. For Sites 1 and 2, where there are significant geologic data, and even for Site 4 where there are some geologic constraints, the scatter among teams is less than one order of magnitude. For Sites 3, 5, 6, 7a, 7b, 8a, and 8b, the individual team curves span three orders of magnitude. These are the sites for which there are little or no data. The calculated hazard for these sites is driven largely by models.

Regarding the latter group of sites, it is important to note that most of the uncertainty relates to the lower portion of the epistemic distribution, as one can verify by noting that the mean and 85th percentile curves are relatively close to each other, whereas the 15th percentile curve is often much lower, if not lower than 10^{-8} (e.g., Figures 8-8 and 8-9). This implies that the experts agree that the hazard at these sites is low or very low, but they do not agree on how low it is.

TABLE 8-1
MEAN DISPLACEMENT HAZARD AT NINE DEMONSTRATION SITES

		Mean Displacement (cm) Annual Exceedance Probability	
Site	**Location**	**10^{-4}**	**10^{-5}**
1	Bow Ridge fault	<0.1	7.8
2	Solitario Canyon fault	<0.1	32
3	Drill Hole Wash fault	<0.1	<0.1
4	Ghost Dance fault	<0.1	<0.1
5	Sundance fault	<0.1	<0.1
6	Unnamed fault west of Dune Wash	<0.1	<0.1
7	100 m east of Solitario Canyon fault		
7a	2-m small fault	<0.1	<0.1
7b	10-cm shear	<0.1	<0.1
7c	fracture	<0.1	<0.1
7d	intact rock	<0.1	<0.1
8	Between Solitario Canyon and Ghost Dance faults		
8a	2-m small fault	<0.1	<0.1
8b	10-cm shear	<0.1	<0.1
8c	fracture	<0.1	<0.1
8d	intact rock	<0.1	<0.1
9	Midway Valley	<0.1	0.1

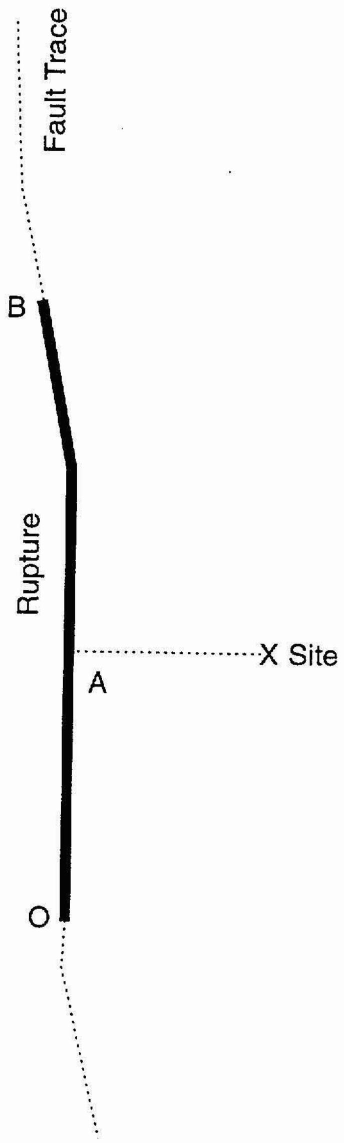

Figure 8-1 Definition of the along-strike location x/L (plane view). OX is the shortest distance from the site to the rupture. x/L is defined as OA/OB or AB/OB, whichever is smallest.

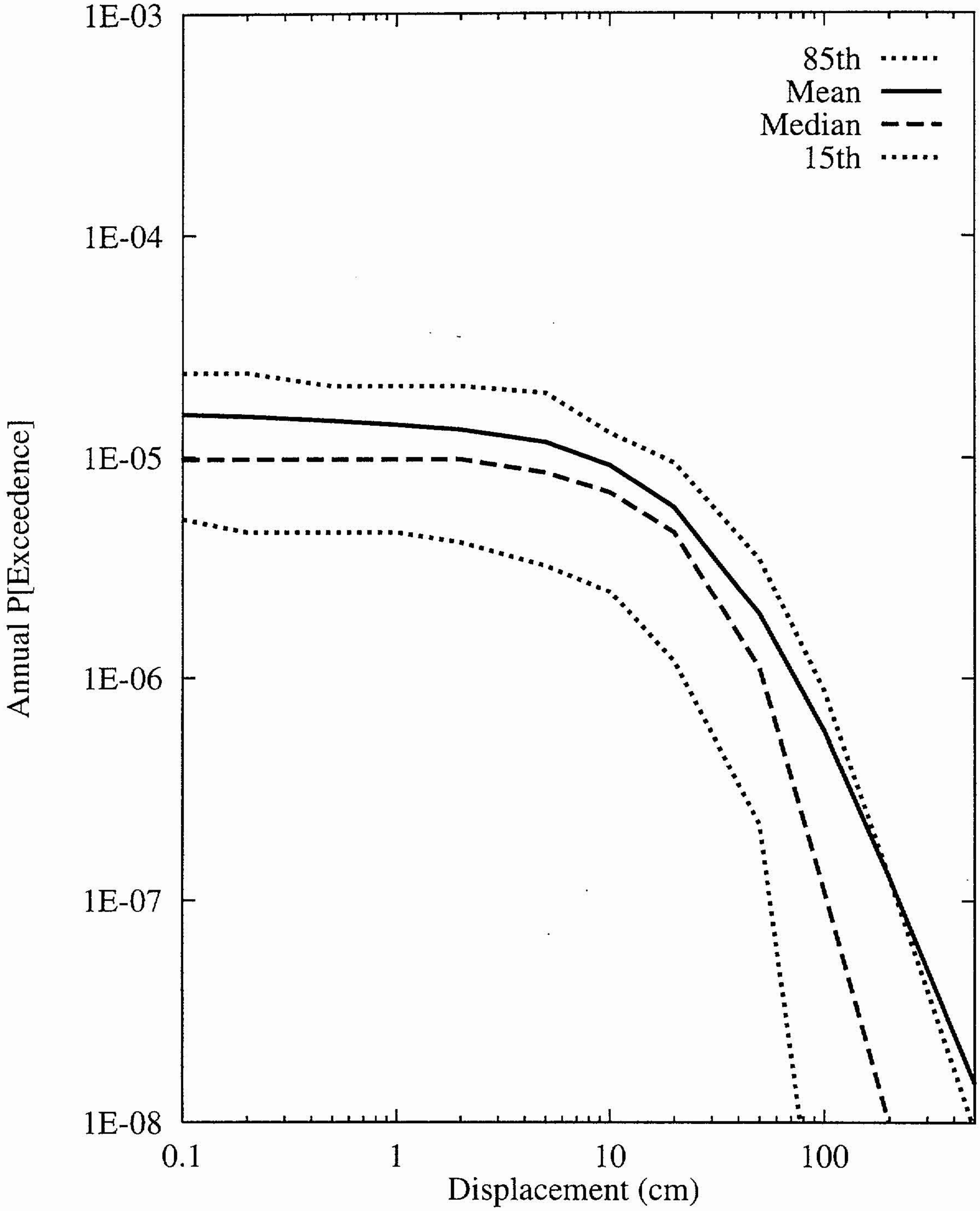

Figure 8-2 Integrated seismic hazard results: summary hazard curves for Site 1, Bow Ridge fault

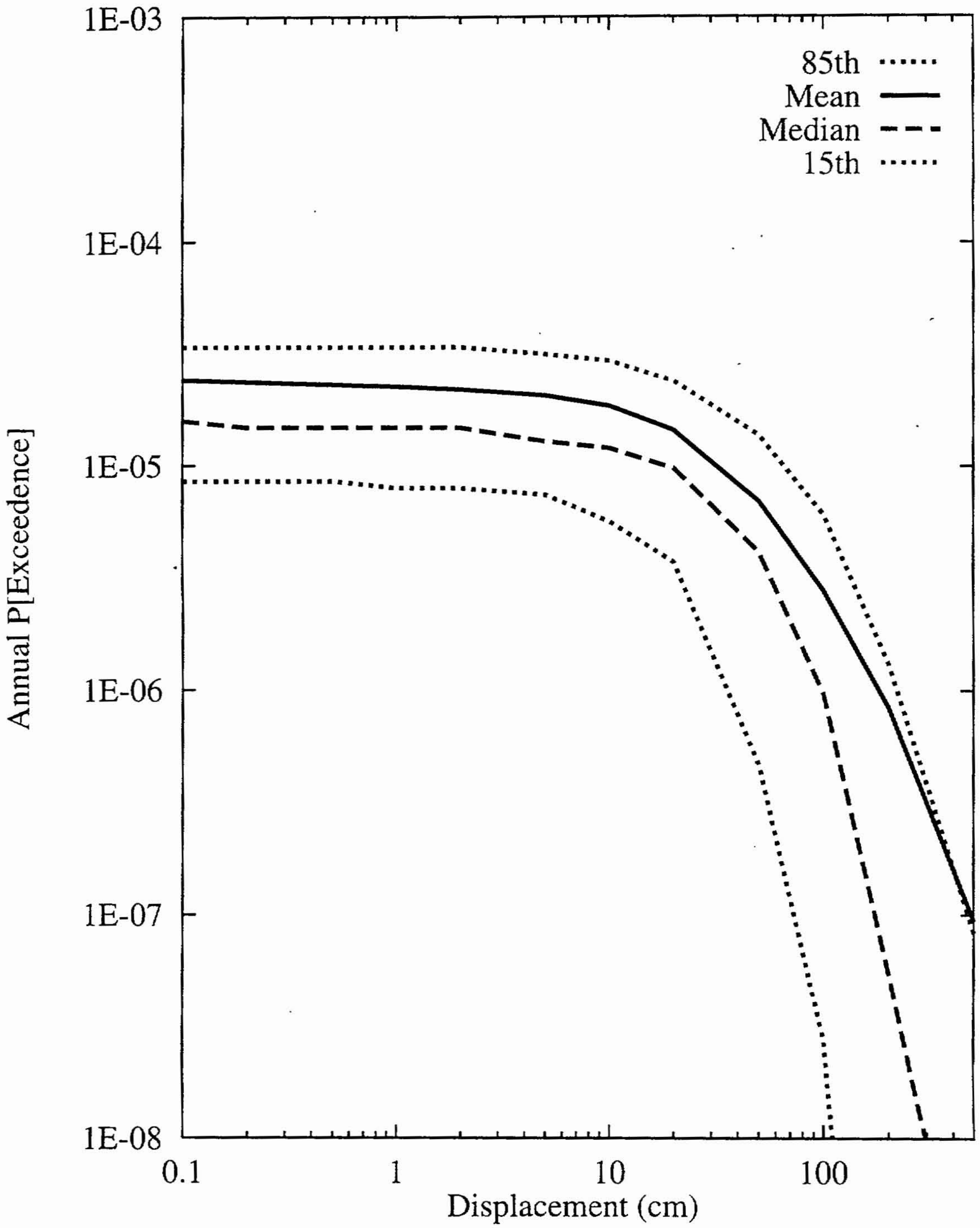

Figure 8-3 Integrated seismic hazard results: summary hazard curves for Site 2, Solitario Canyon fault

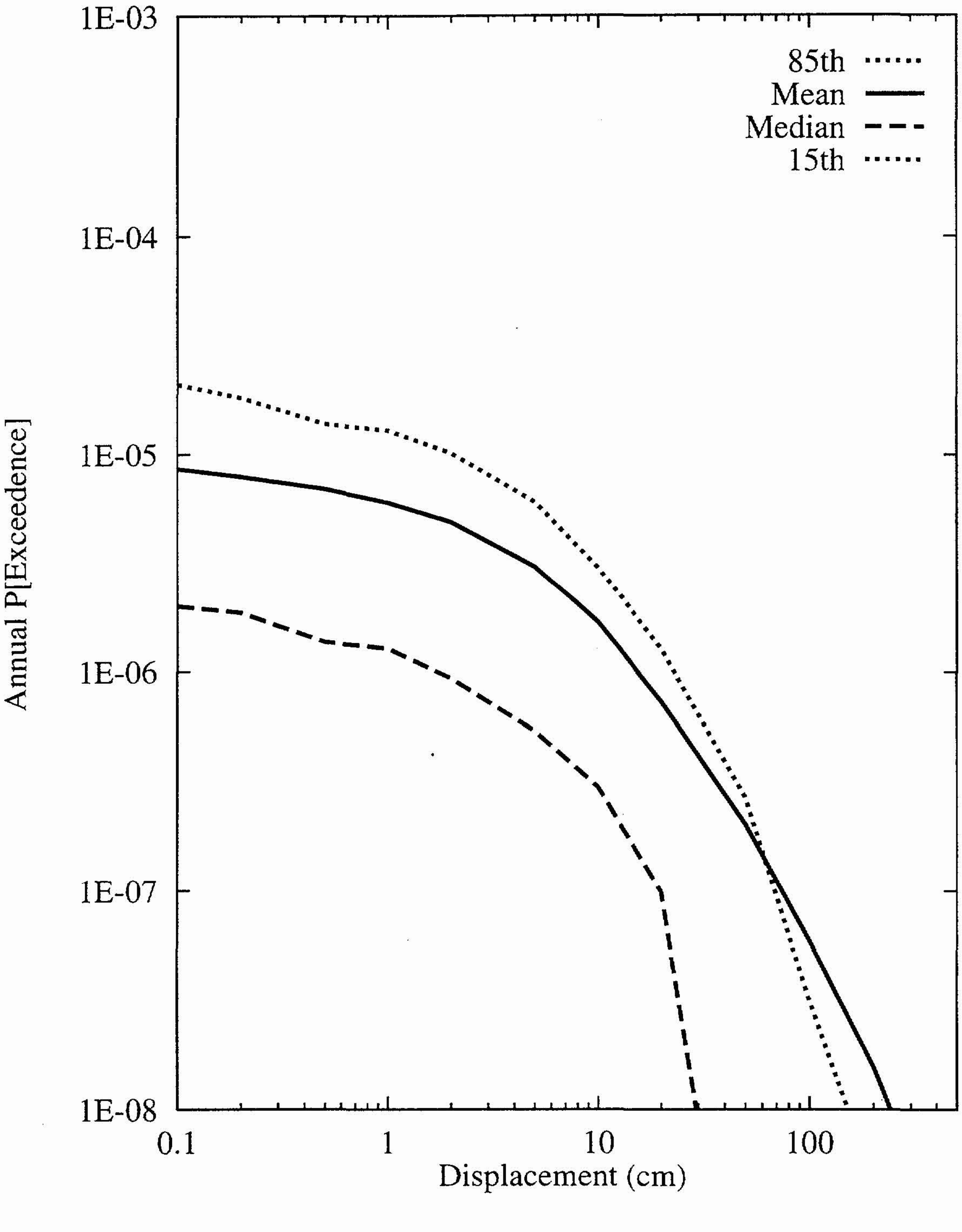

Figure 8-4 Integrated seismic hazard results: summary hazard curves for Site 3, Drill Hole Wash fault

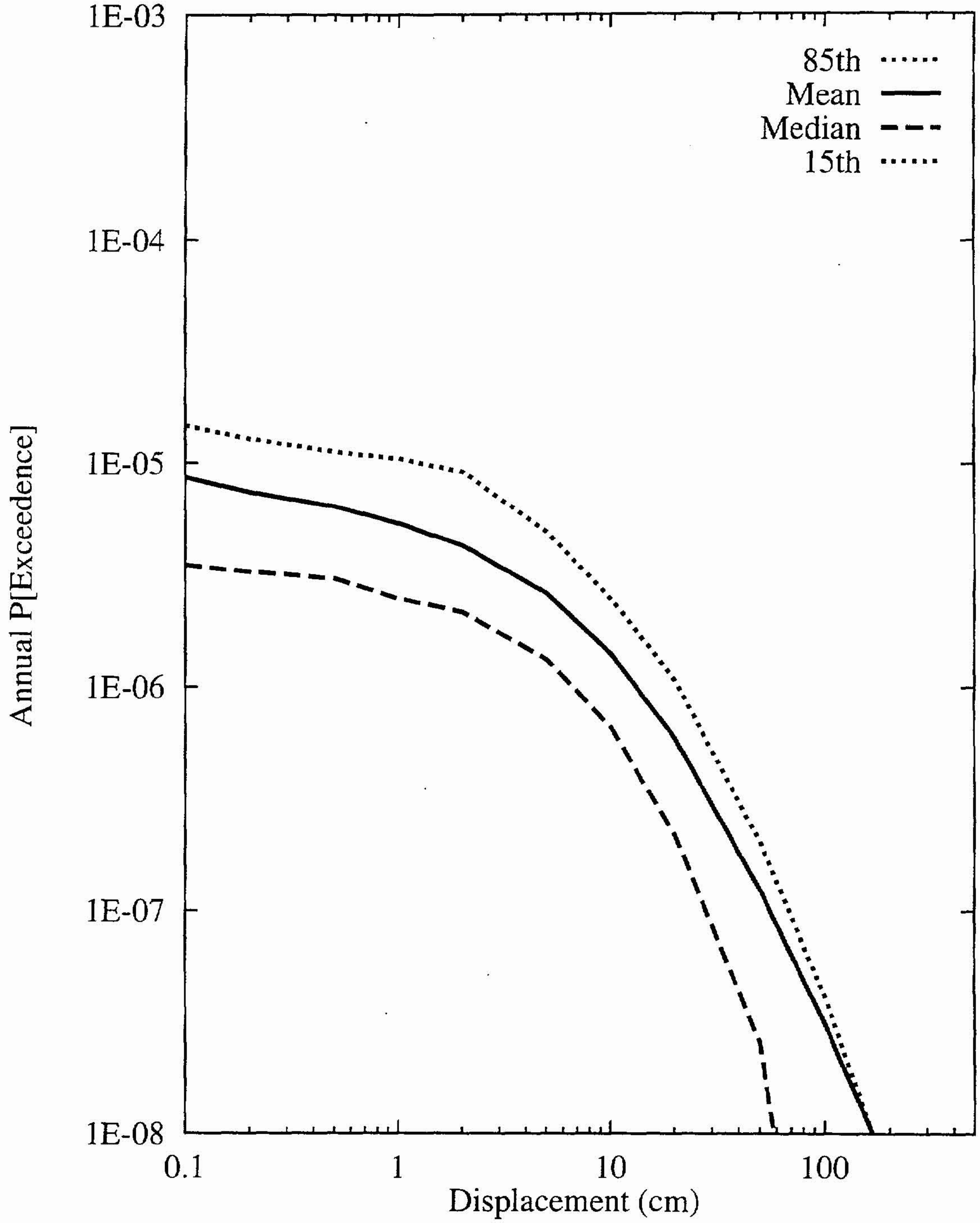

Figure 8-5 Integrated seismic hazard results: summary hazard curves for Site 4, Ghost Dance fault

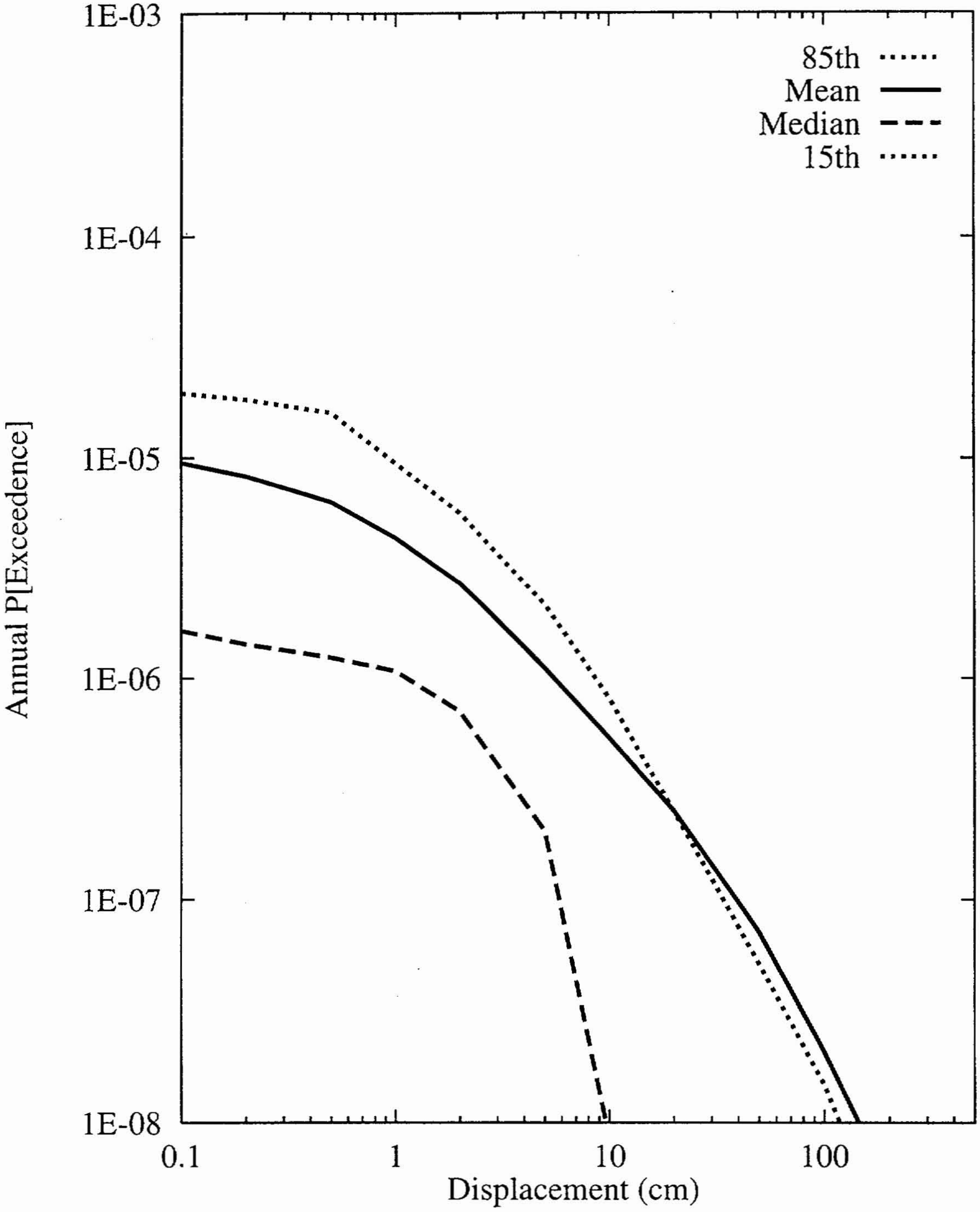

Figure 8-6 Integrated seismic hazard results: summary hazard curves for Site 5, Sundance fault

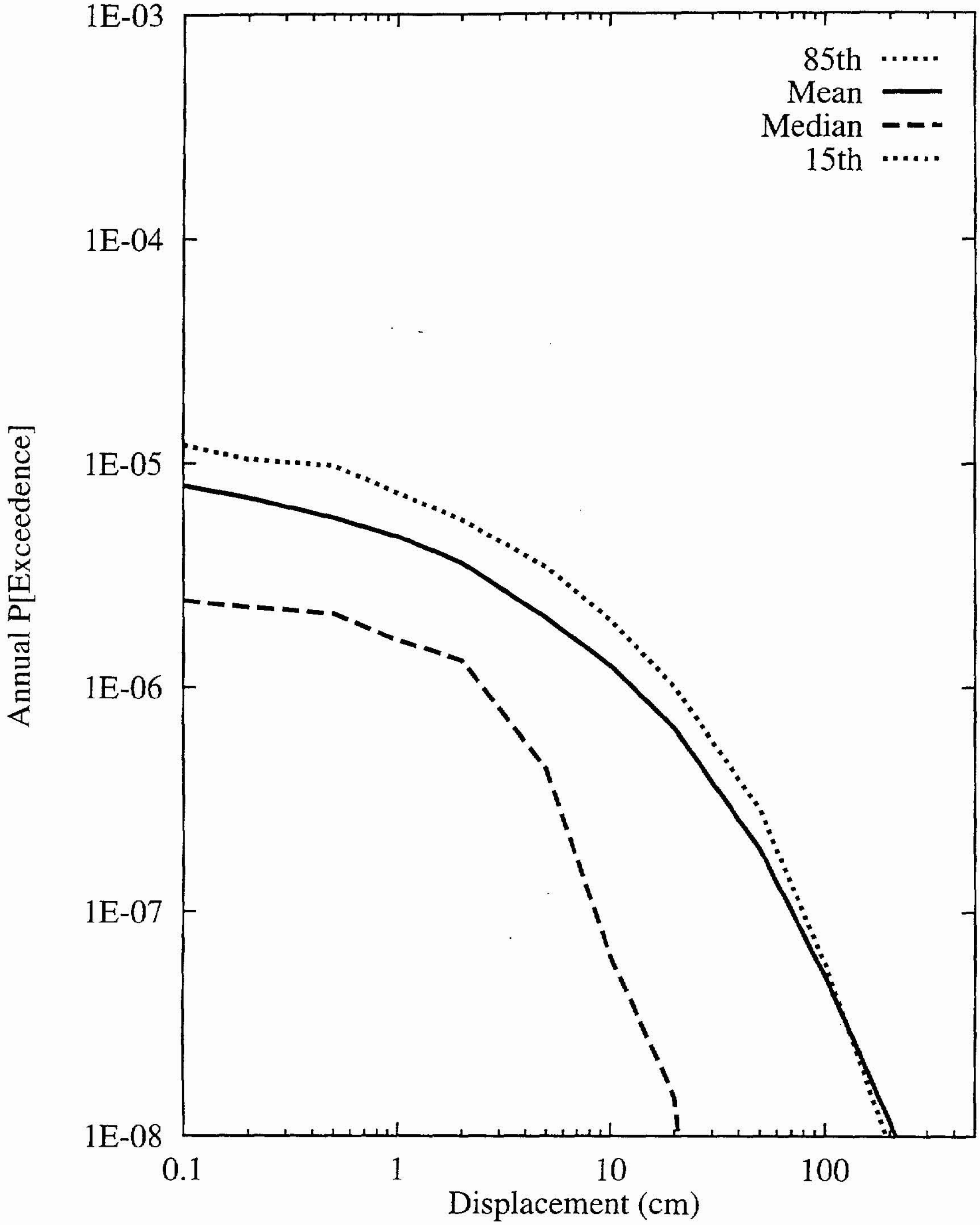

Figure 8-7 Integrated seismic hazard results: summary hazard curves for Site 6, unnamed fault west of Dune Wash

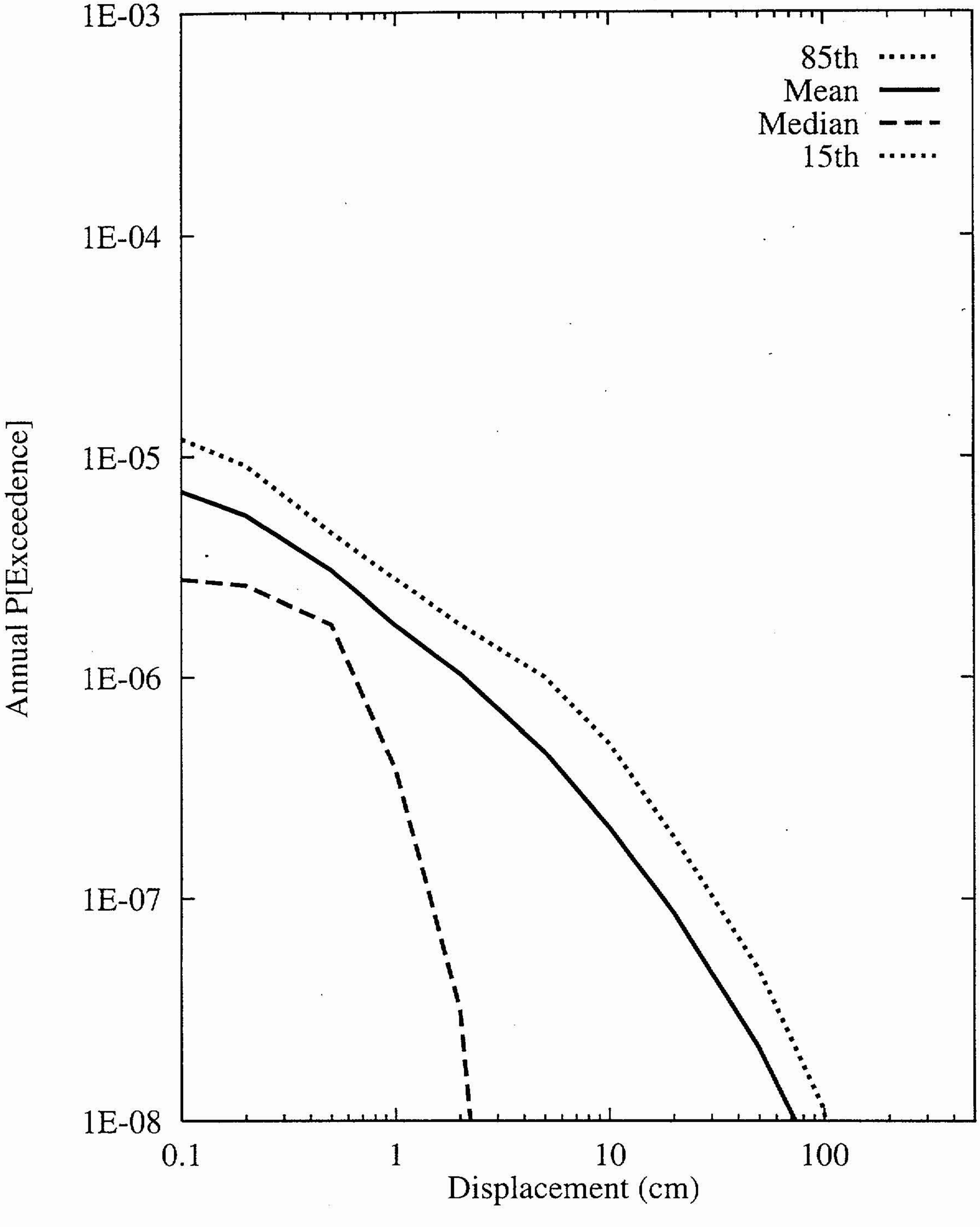

Figure 8-8 Integrated seismic hazard results: summary hazard curves for Site 7a, 100m east of Solitario Canyon fault (2m cumulative displacement)

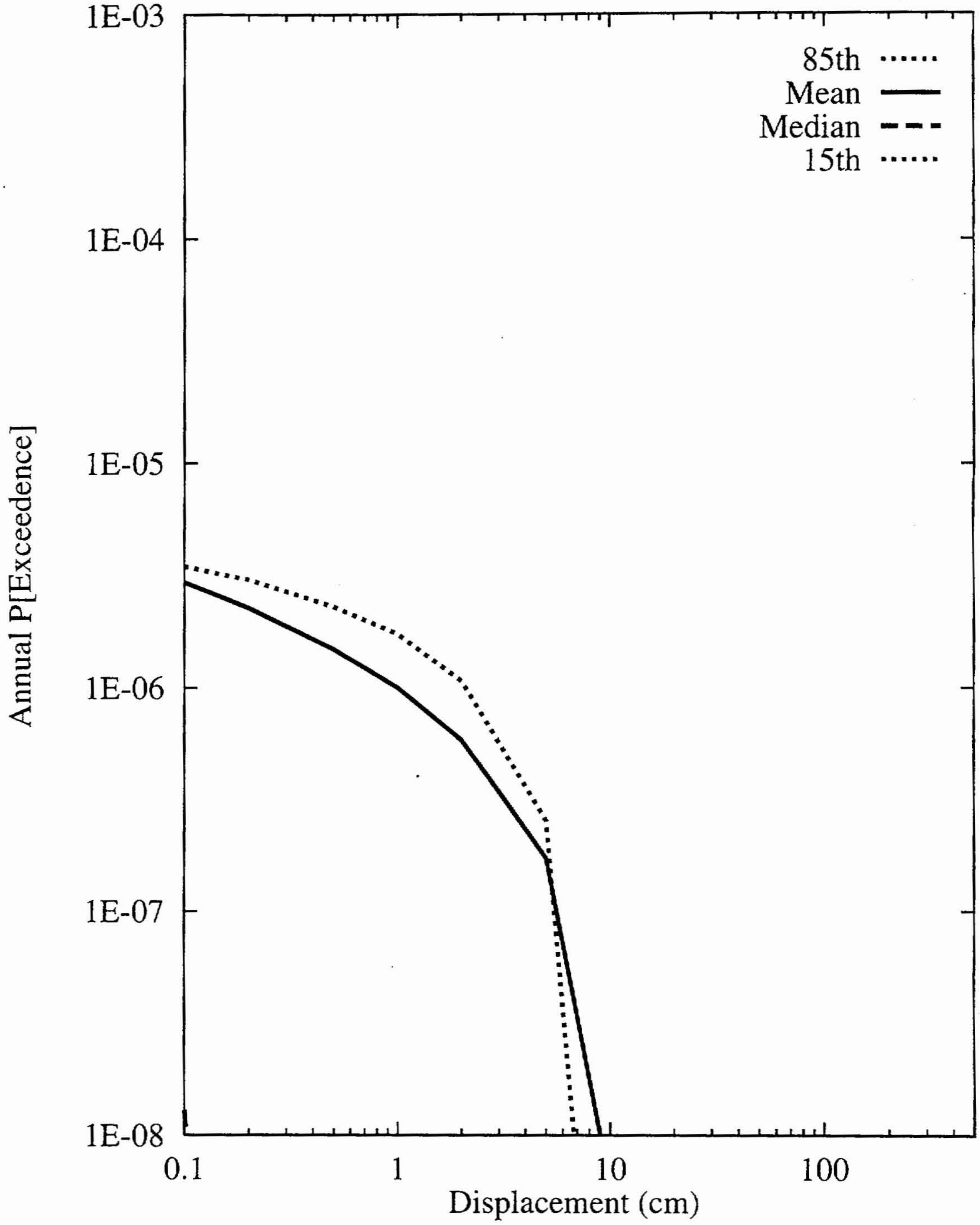

Figure 8-9 Integrated seismic hazard results: summary hazard curves for Site 7b, 100m east of Solitario Canyon fault (10cm cumulative displacement)

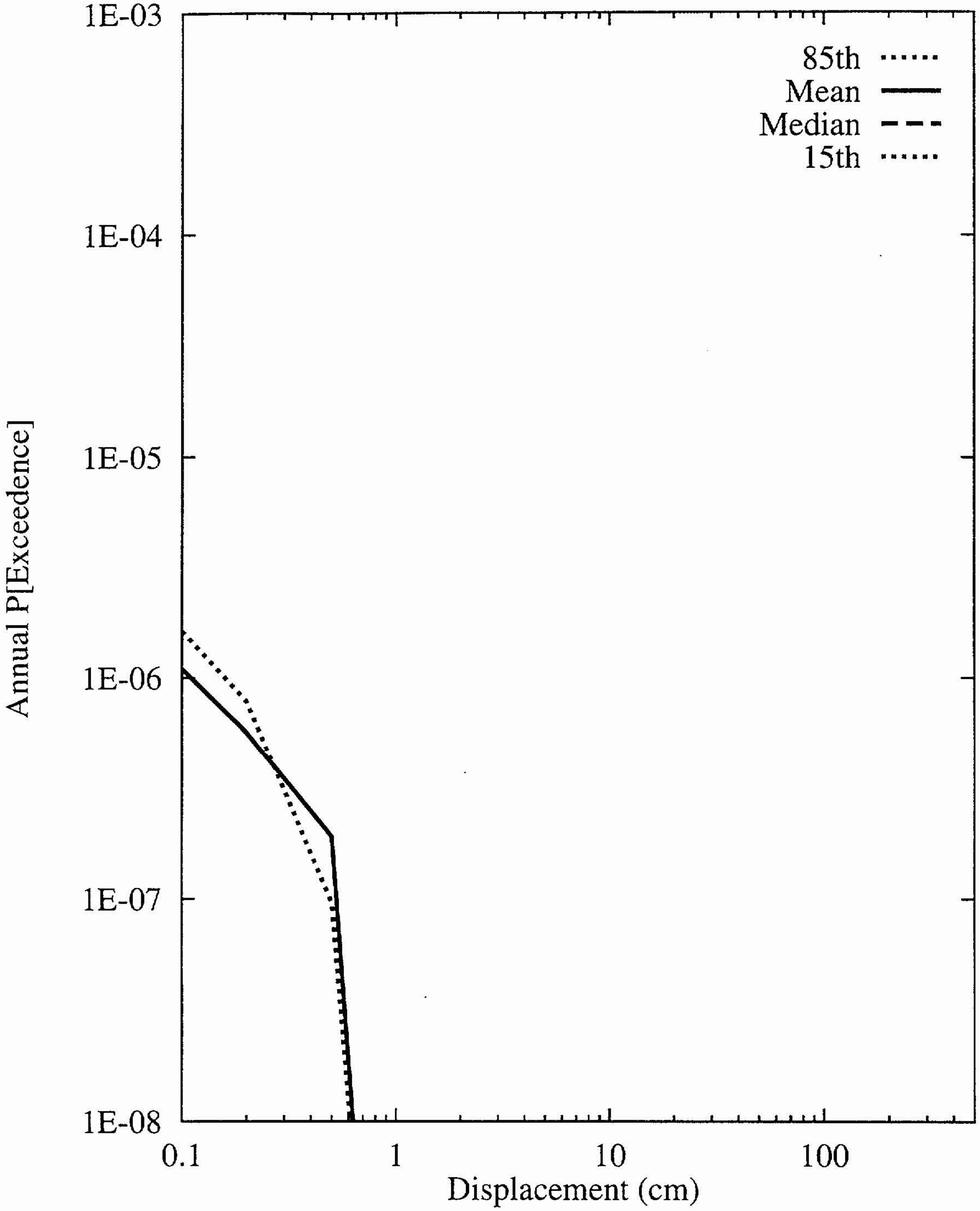

Figure 8-10 Integrated seismic hazard results: summary hazard curves for Site 7c, 100m east of Solitario Canyon fault (no measurable cumulative displacement)

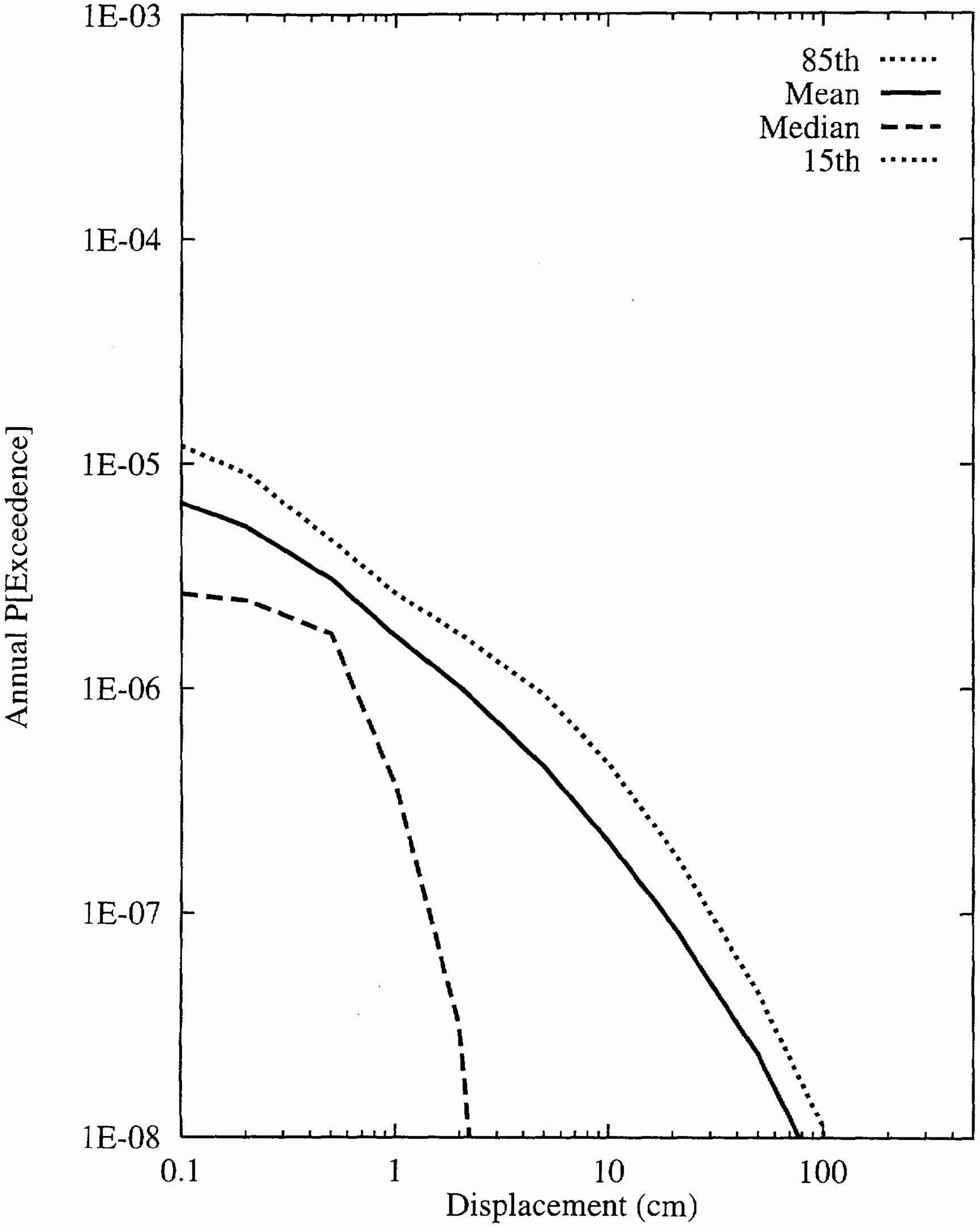

Figure 8-11 Integrated seismic hazard results: summary hazard curves for Site 8a, midway between the Ghost Dance and Solitario Canyon faults (2m cumulative displacement)

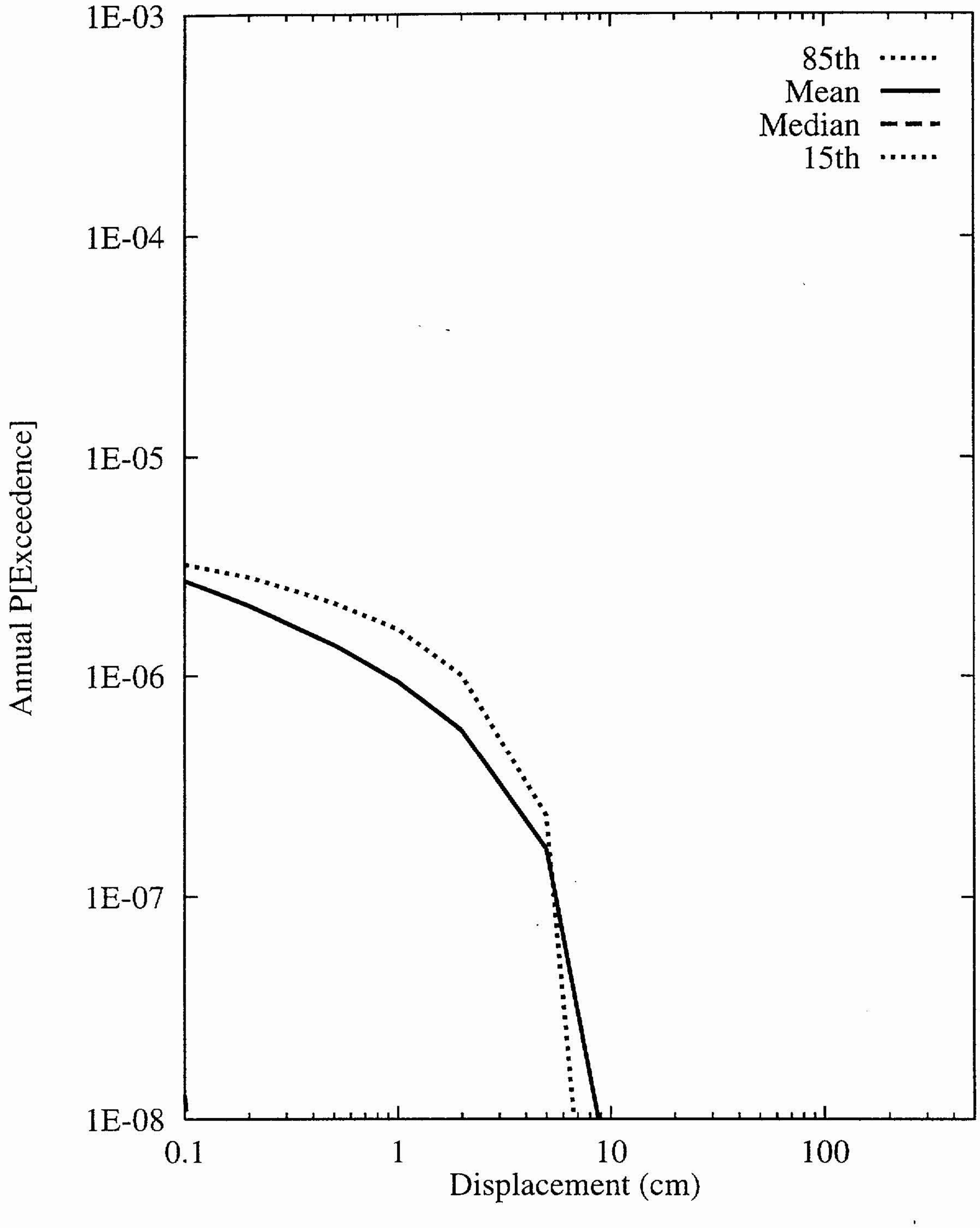

Figure 8-12 Integrated seismic hazard results: summary hazard curves for Site 8b, midway between the Ghost Dance and Solitario Canyon faults (10cm cumulative displacement)

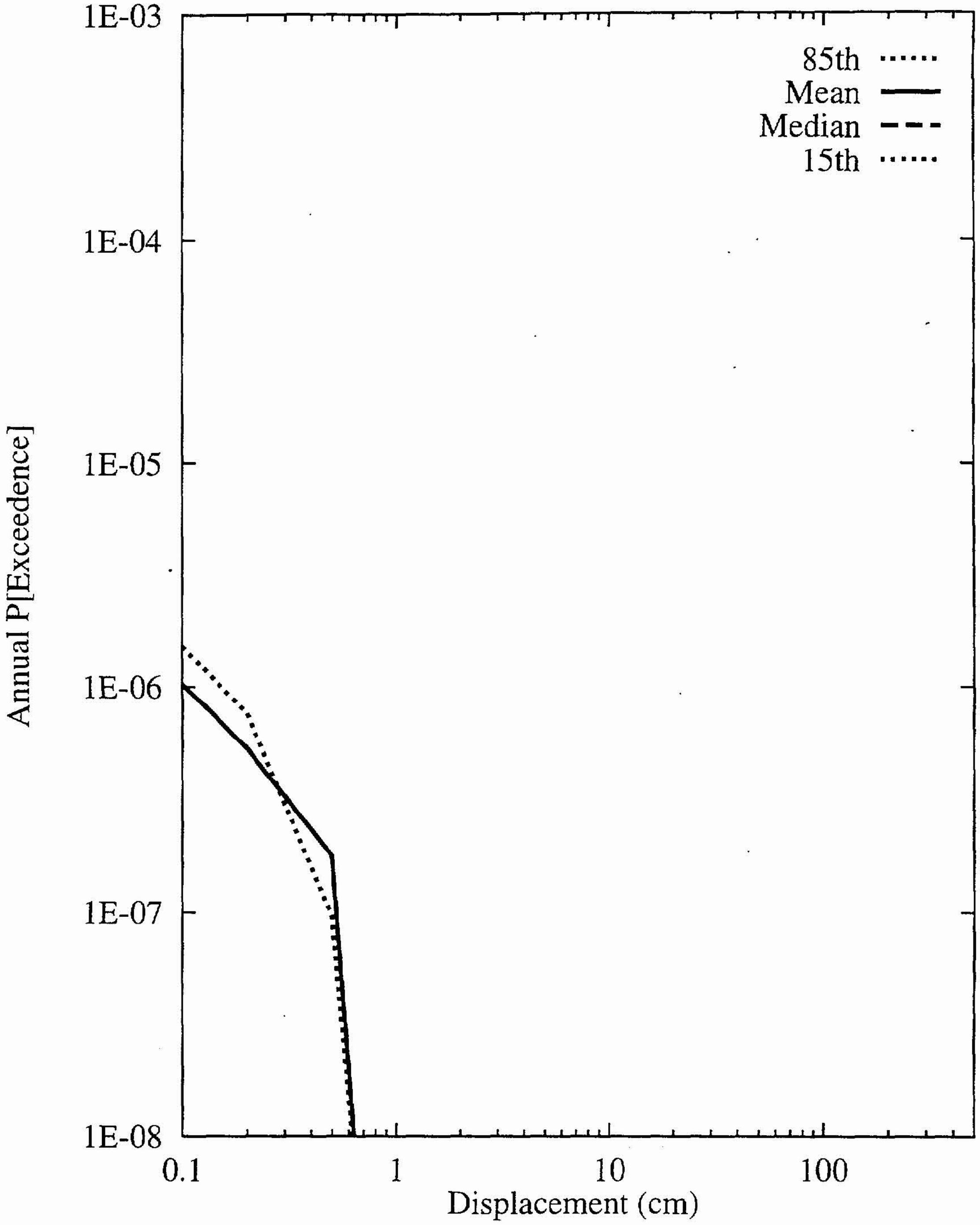

Figure 8-13 Integrated seismic hazard results: summary hazard curves for Site 8c, midway between the Ghost Dance and Solitario Canyon faults (no measurable cumulative displacement)

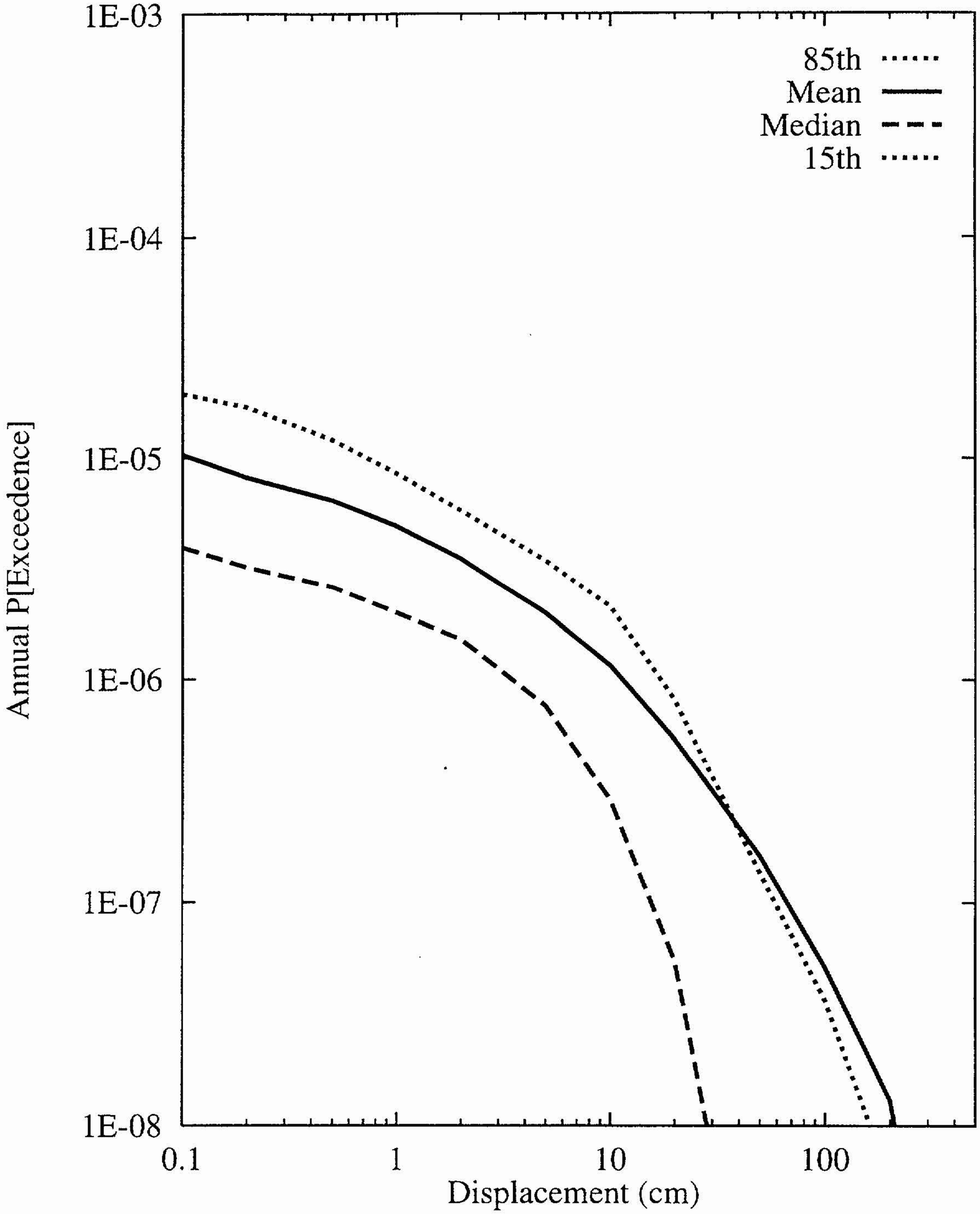

Figure 8-14 Integrated seismic hazard results: summary hazard curves for Site 9, Midway Valley

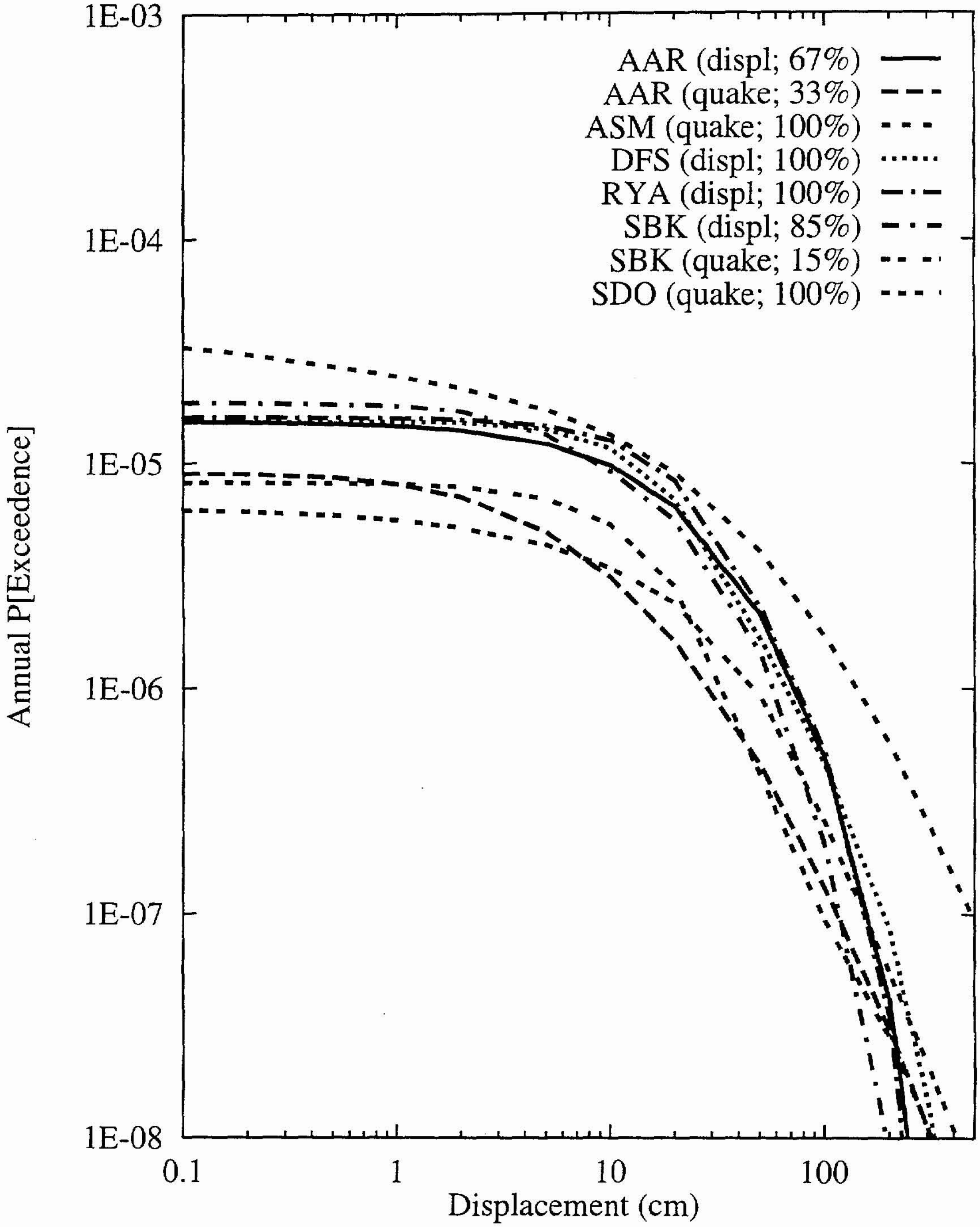

Figure 8-15 Mean hazard by teams and approaches for Site 1, Bow Ridge fault

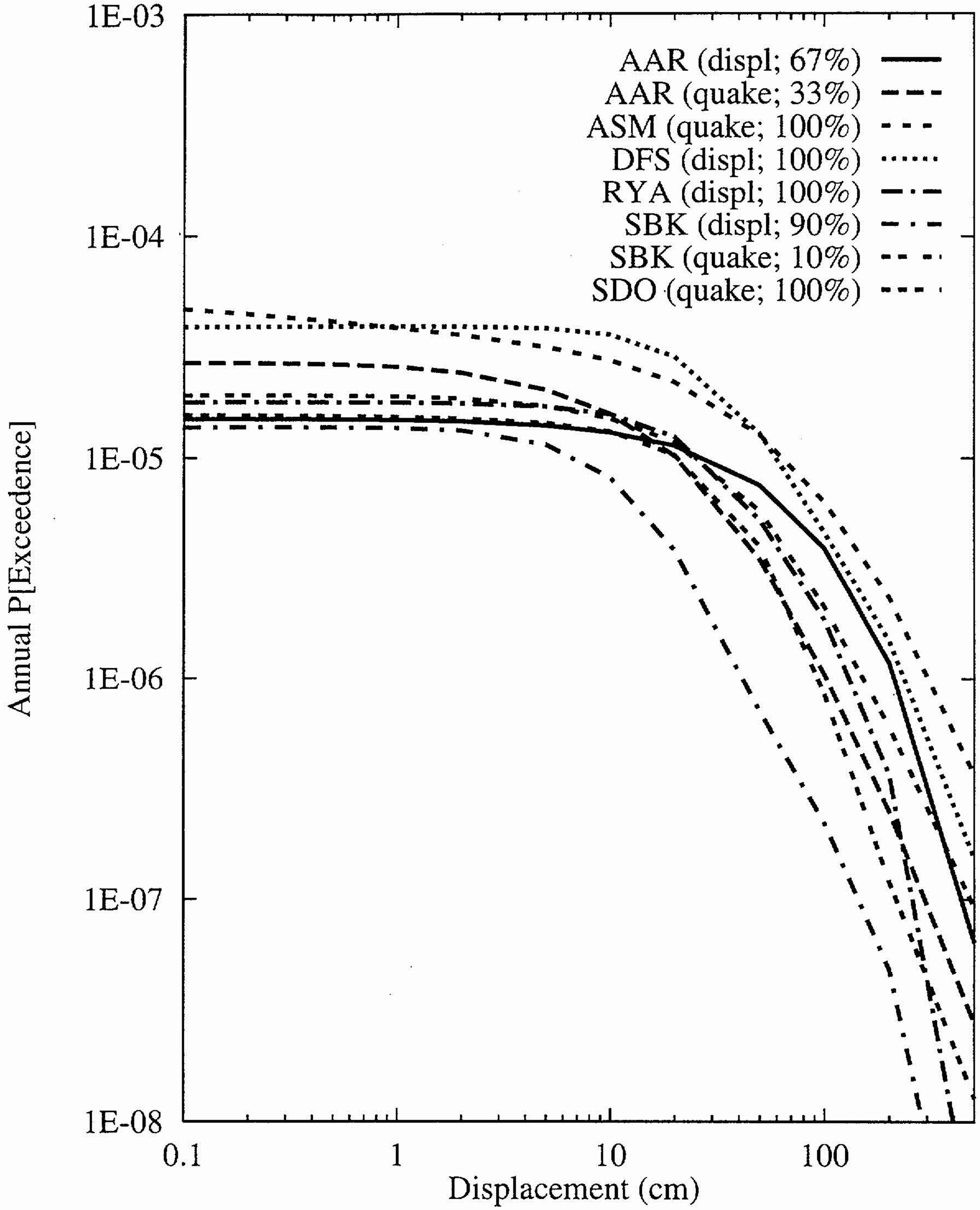

Figure 8-16 Mean hazard by teams and approaches for Site 2, Solitario Canyon fault

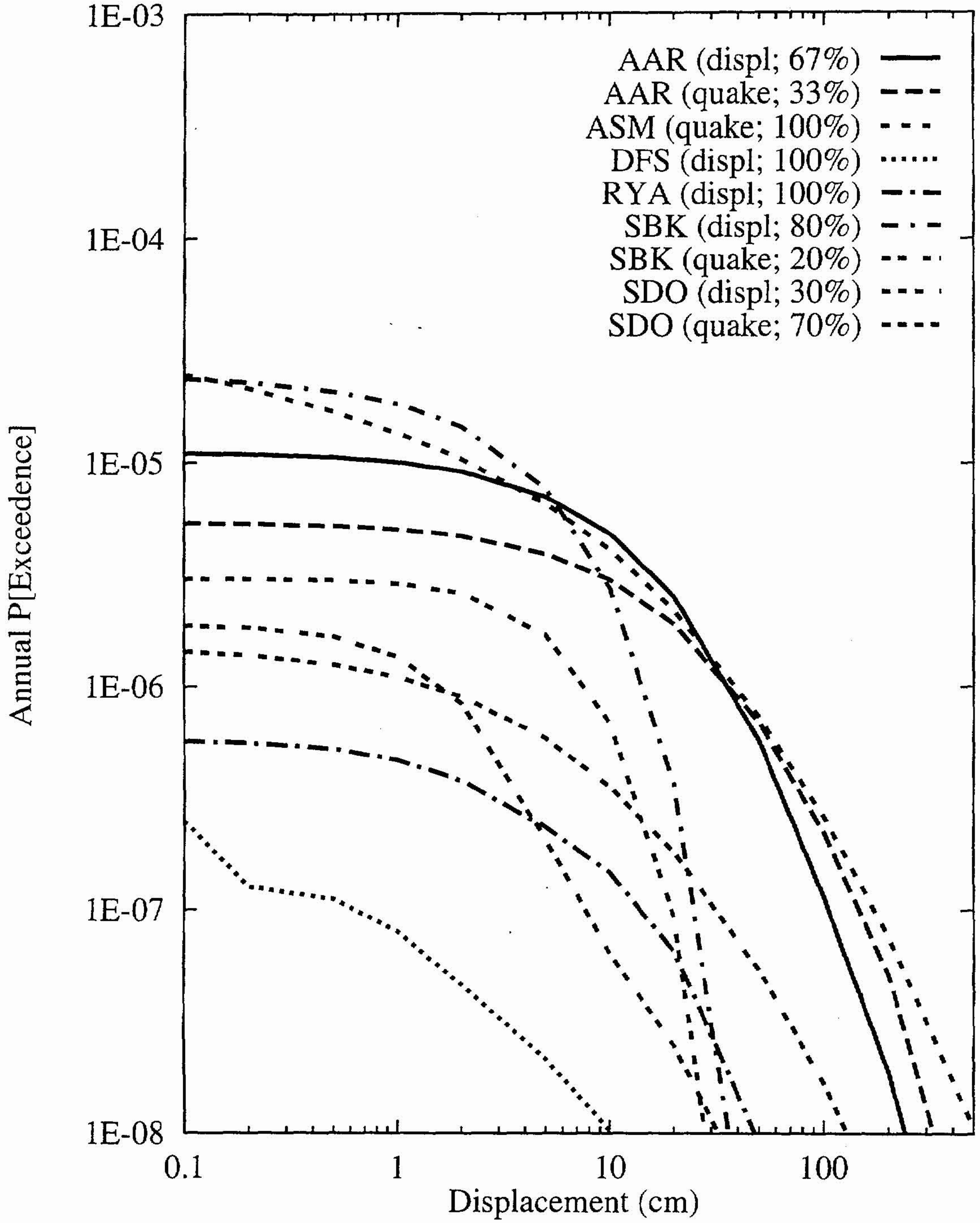

Figure 8-17 Mean hazard by teams and approaches for Site 3, Drill Hole Wash fault

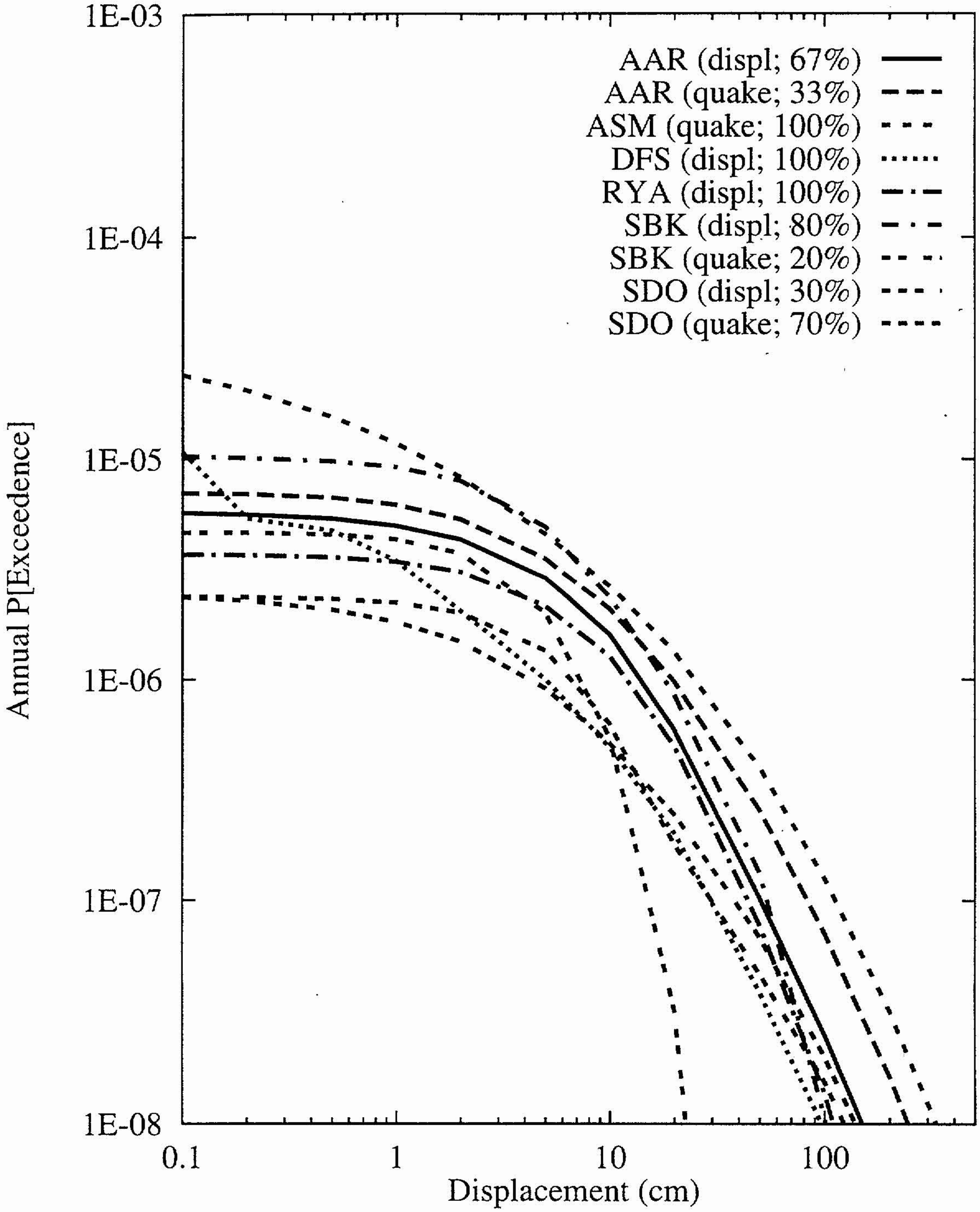

Figure 8-18 Mean hazard by teams and approaches for Site 4, Ghost Dance fault

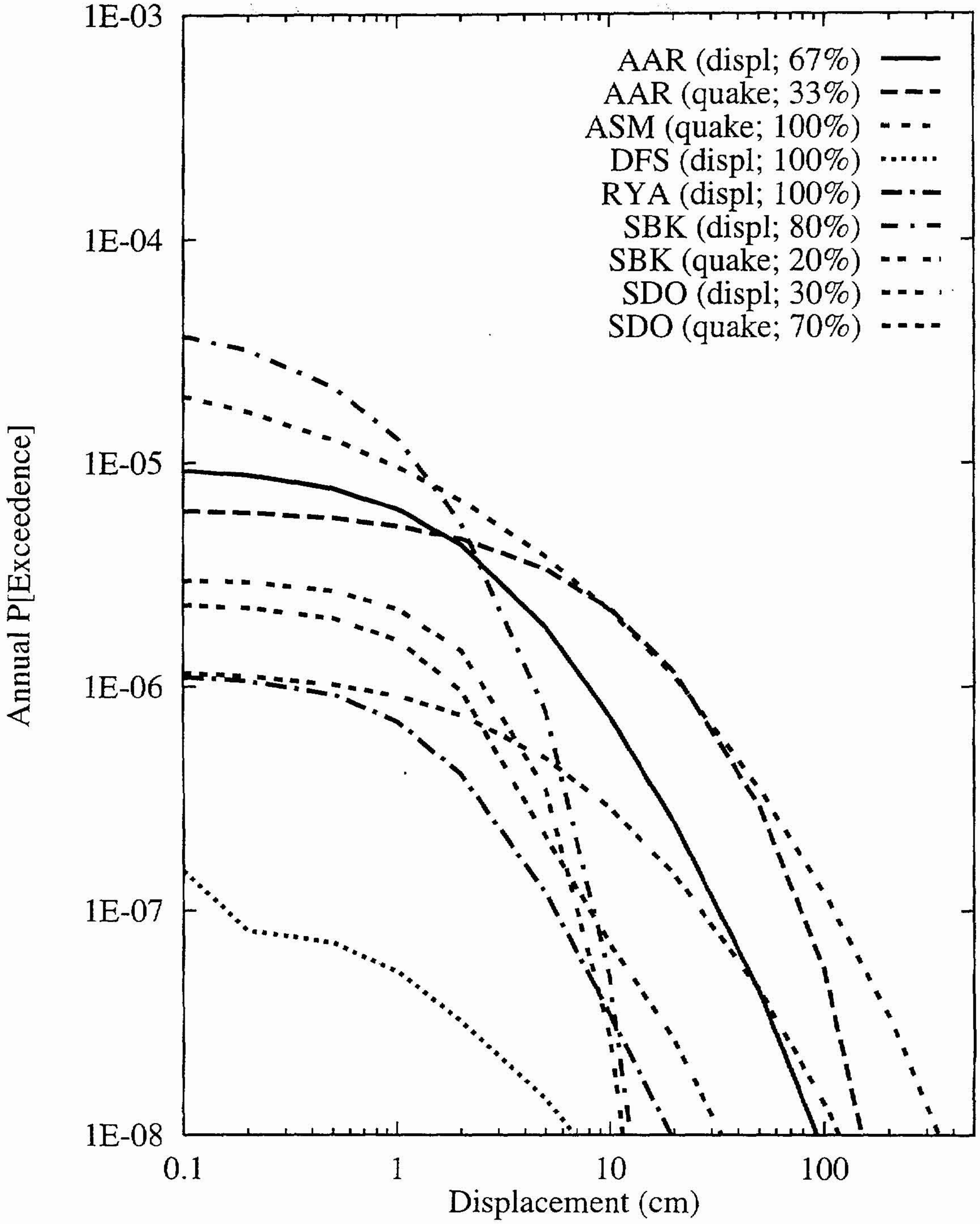

Figure 8-19 Mean hazard by teams and approaches for Site 5, Sundance fault

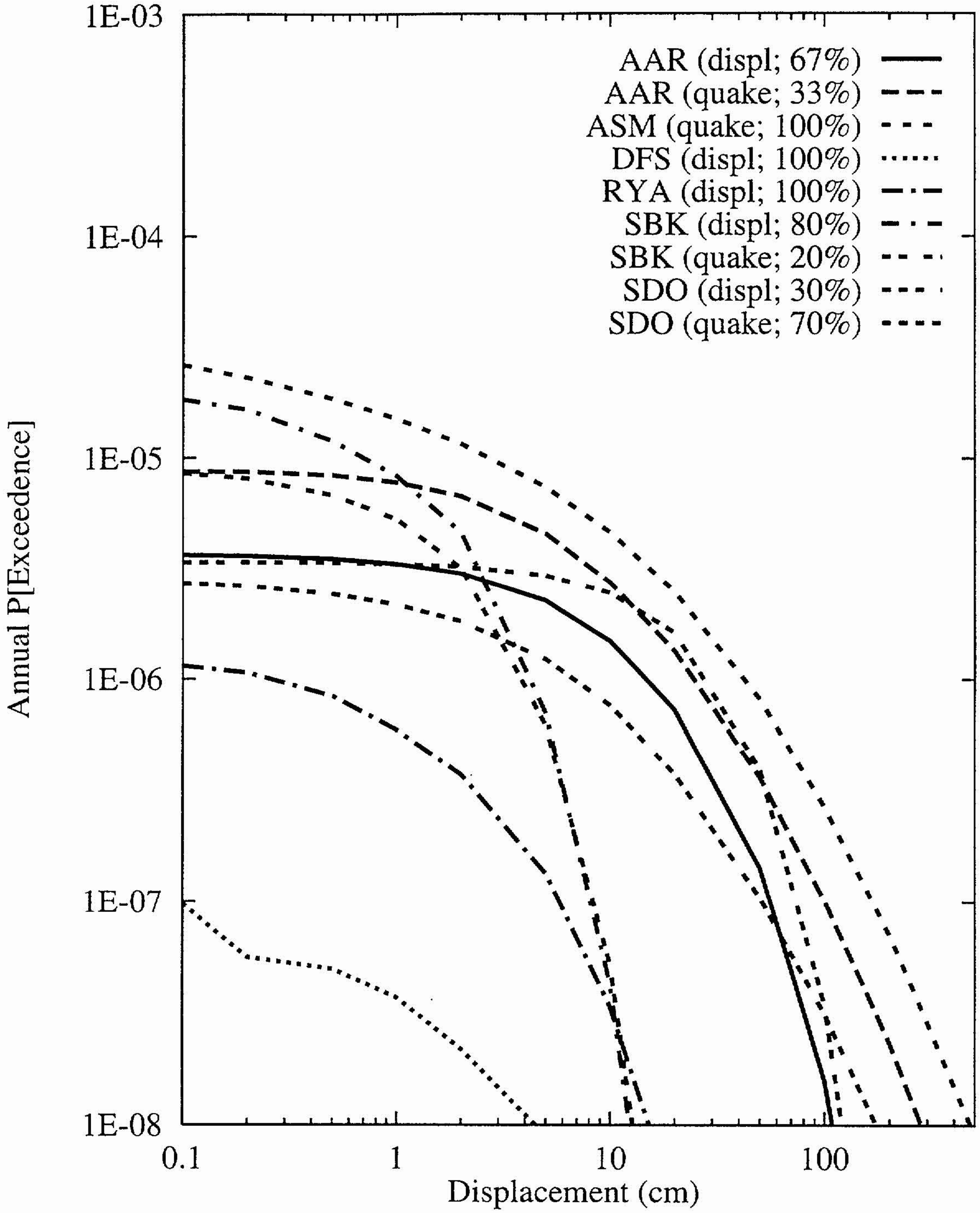

Figure 8-20 Mean hazard by teams and approaches for Site 6,
unnamed fault west of Dune Wash fault

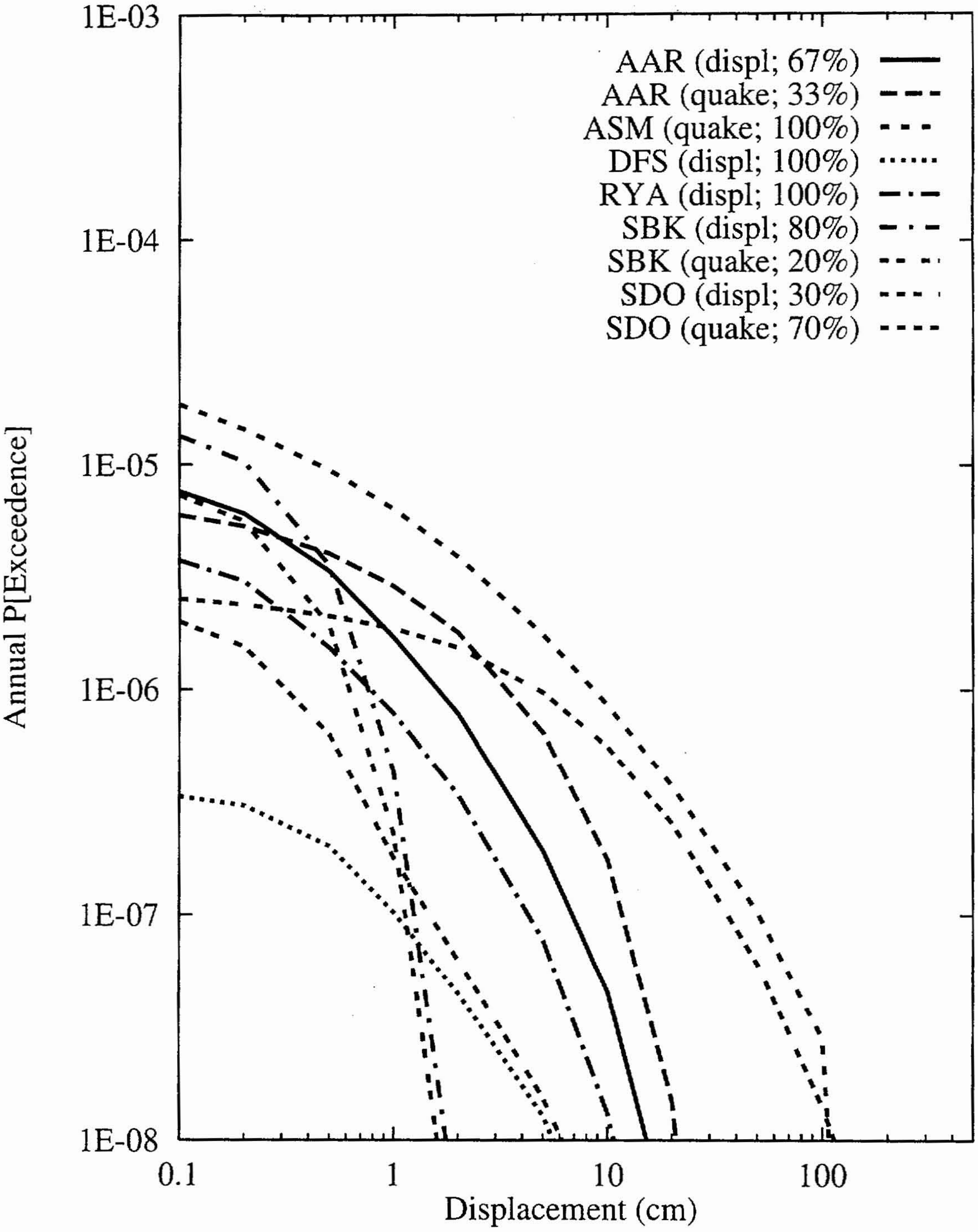

Figure 8-21 Mean hazard by teams and approaches for Site 7a, 100m east of Solitario Canyon fault (2m cumulative displacement)

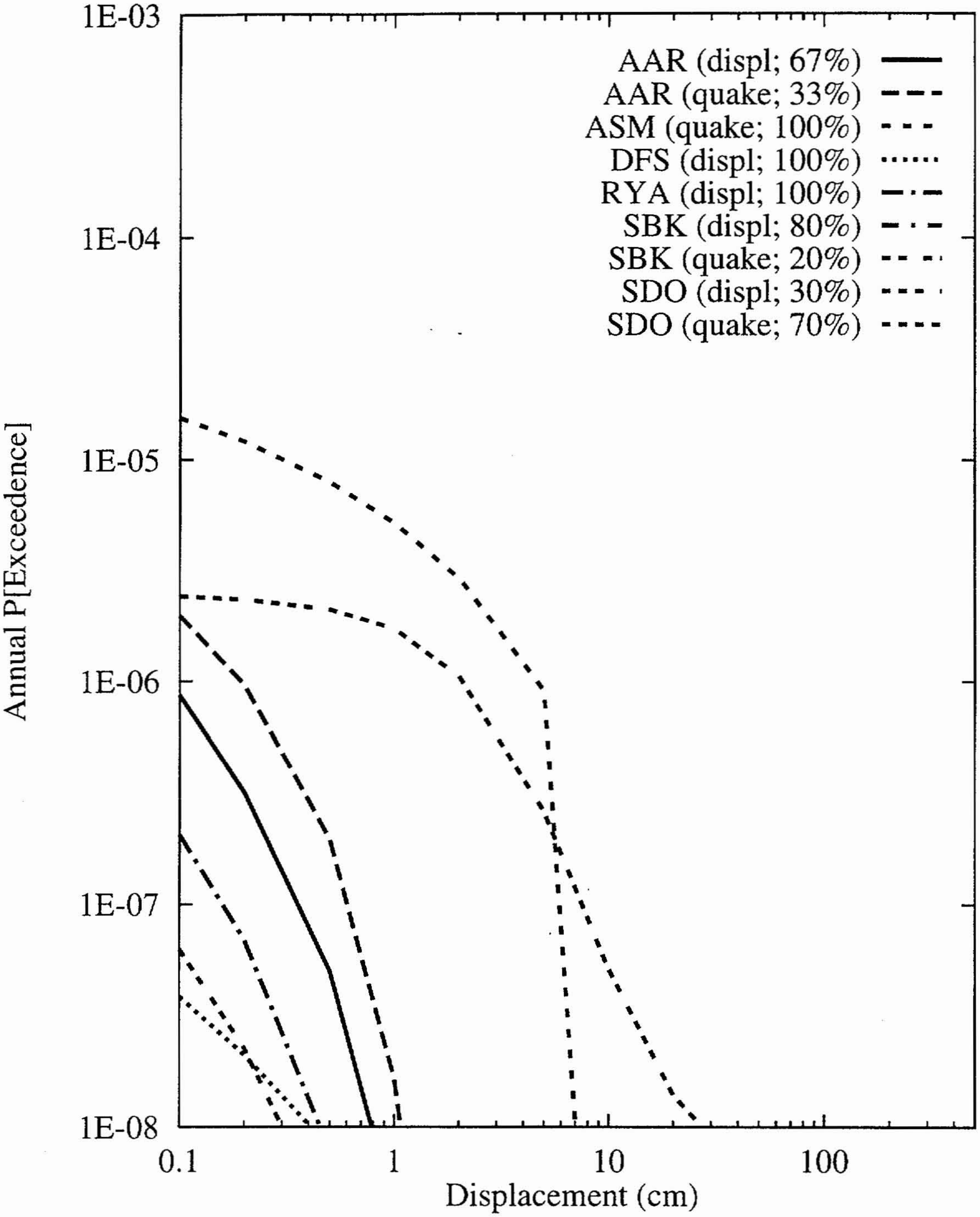

Figure 8-22 Mean hazard by teams and approaches for Site 7b, 100m east of Solitario Canyon fault (10cm cumulative displacement)

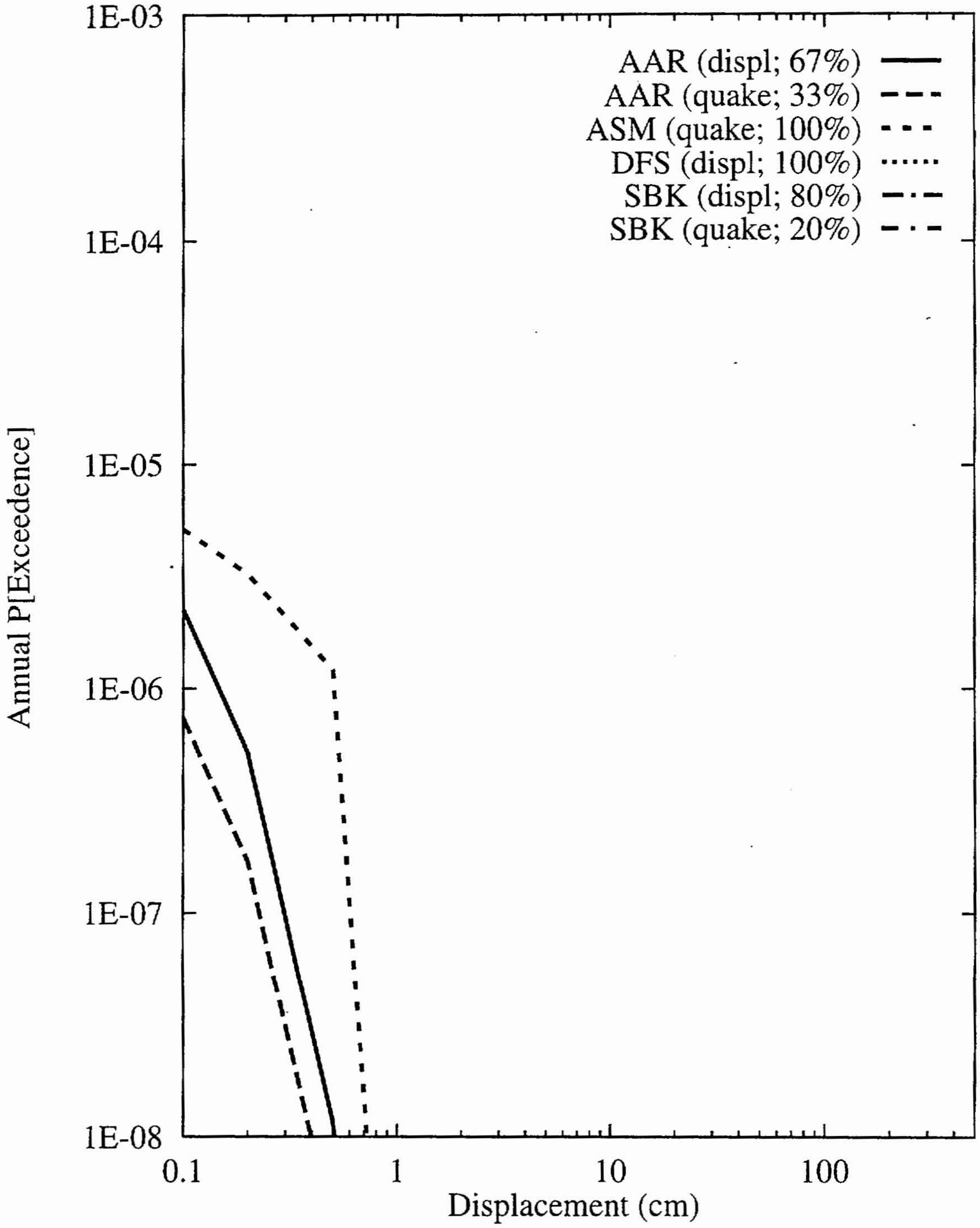

Figure 8-23 Mean hazard by teams and approaches for Site 7c, 100m east of Solitario Canyon fault (no measurable cumulative displacement)

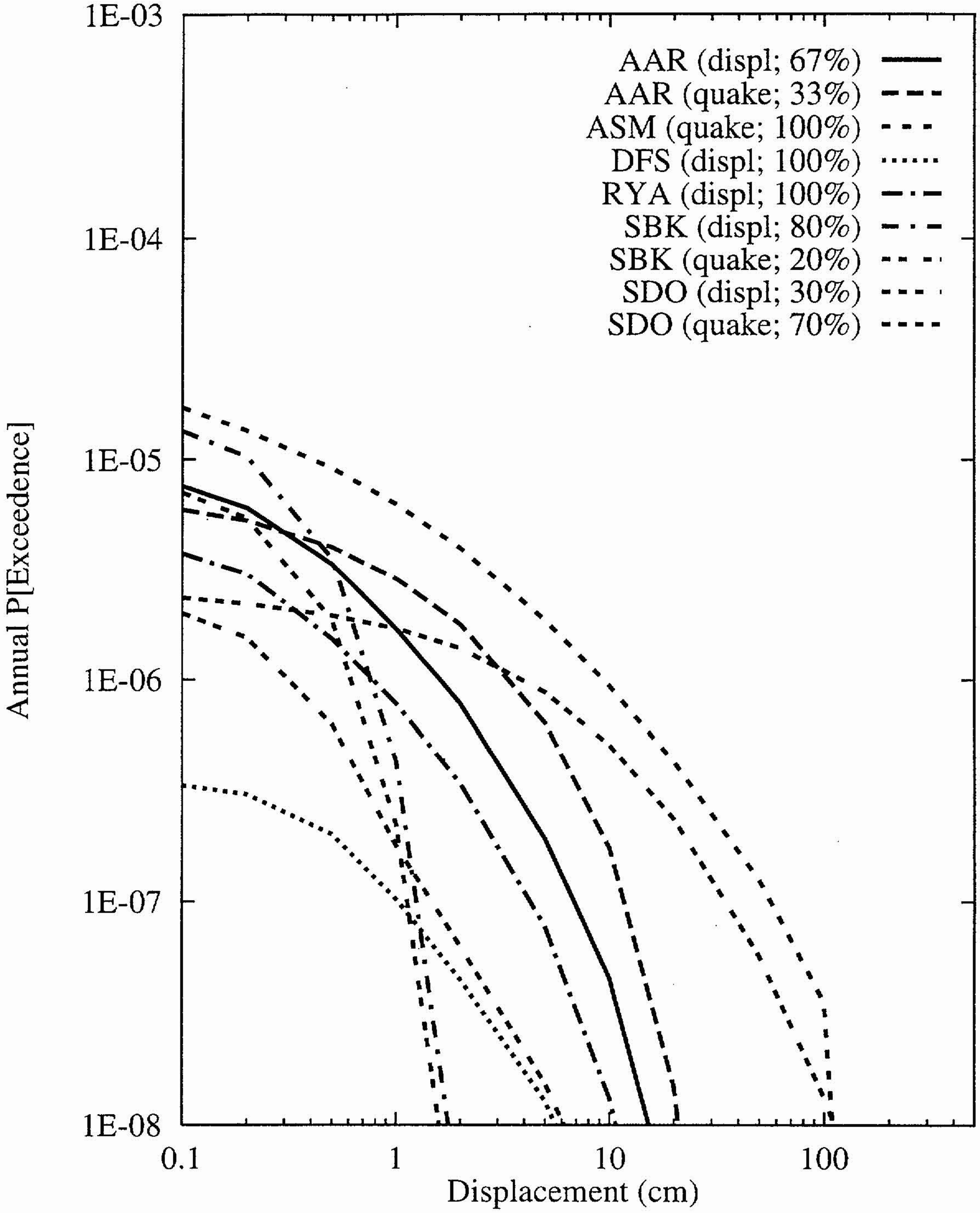

Figure 8-24 Mean hazard by teams and approaches for Site 8a, midway between the Ghost Dance and Solitario Canyon faults (2m cumulative displacement)

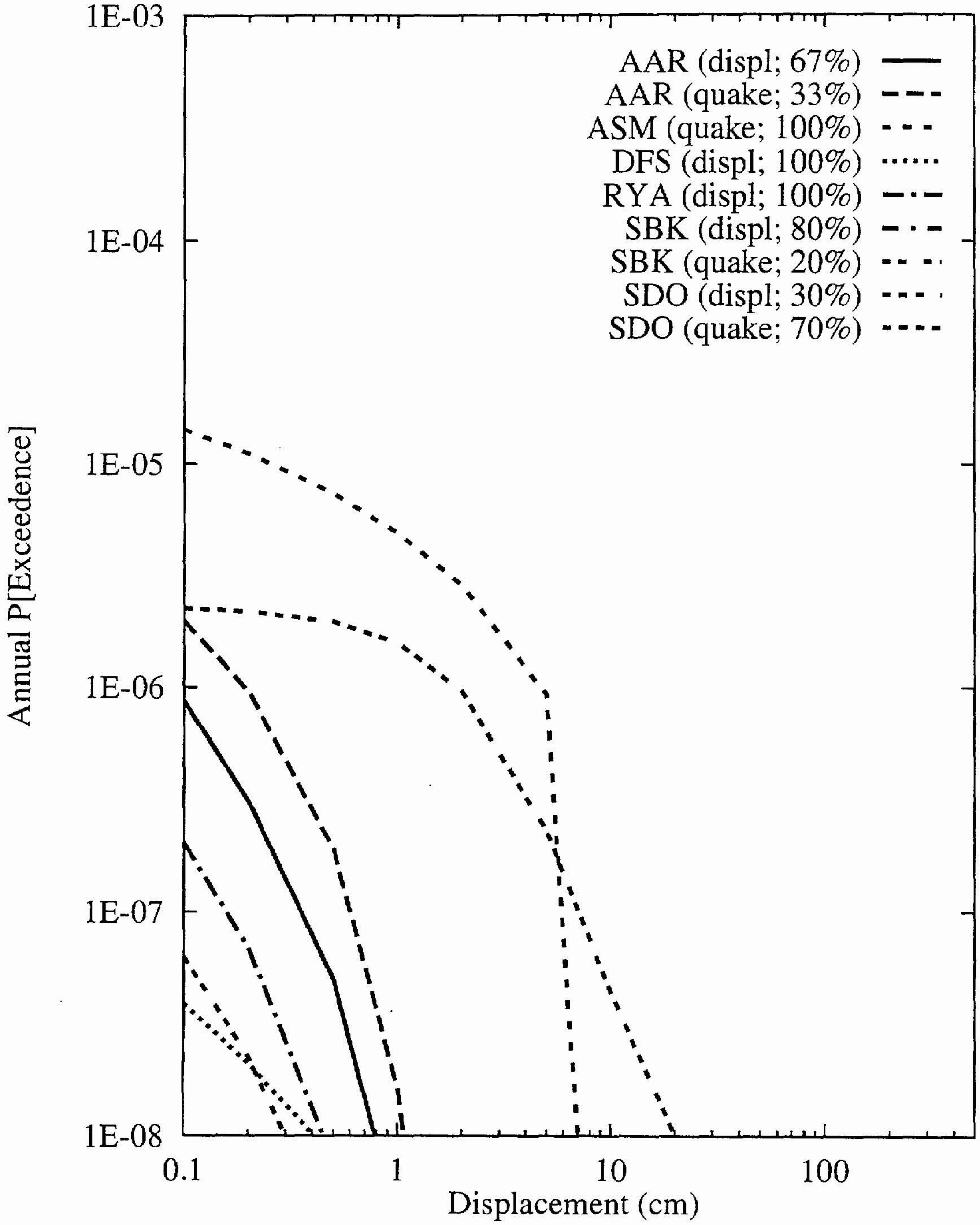

Figure 8-25 Mean hazard by teams and approaches for Site 8b, midway between the Ghost Dance and Solitario Canyon faults (10cm cumulative displacement)

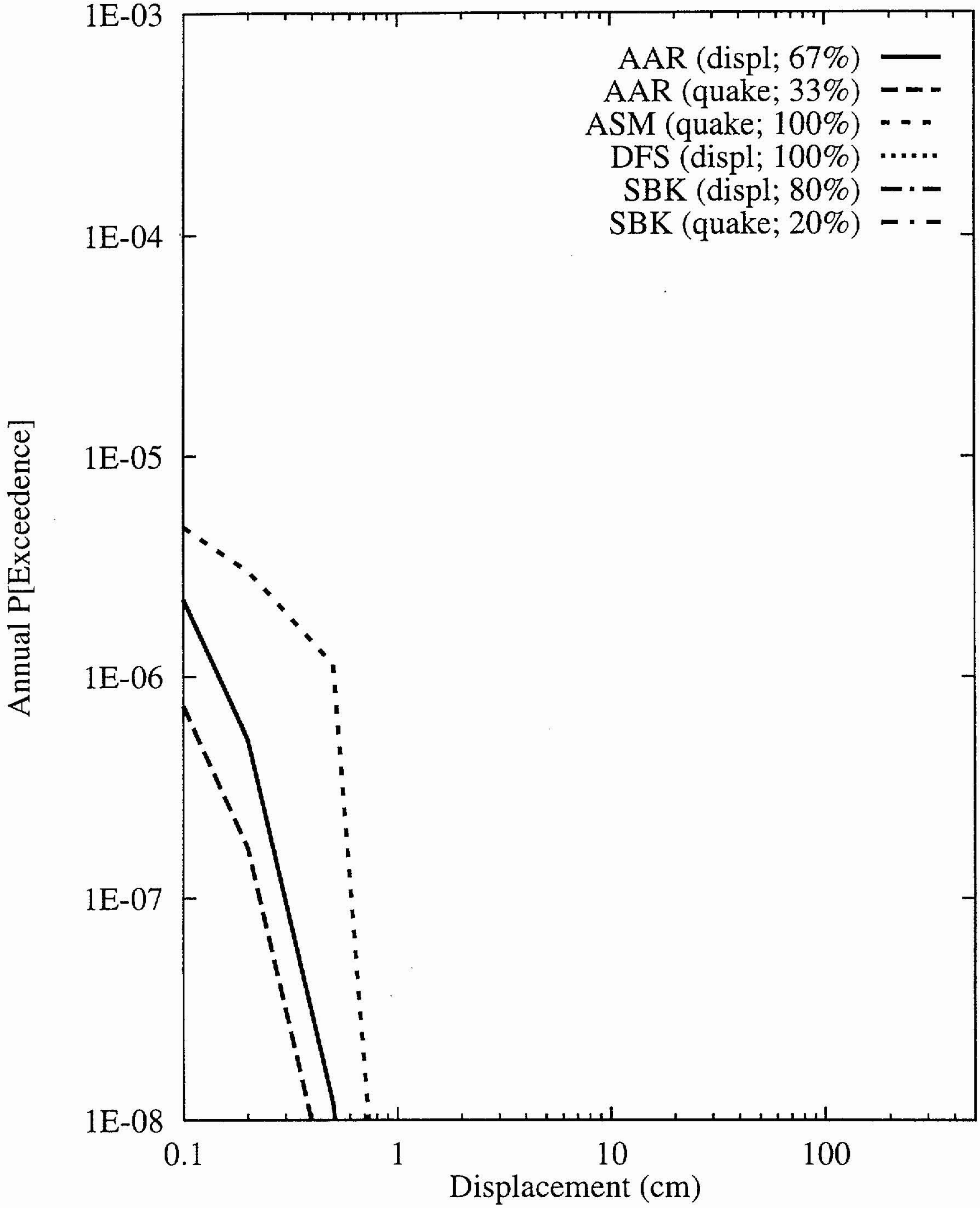

Figure 8-26 Mean hazard by teams and approaches for Site 8c, midway between the Ghost Dance and Solitario Canyon faults (no measurable cumulative displacement)

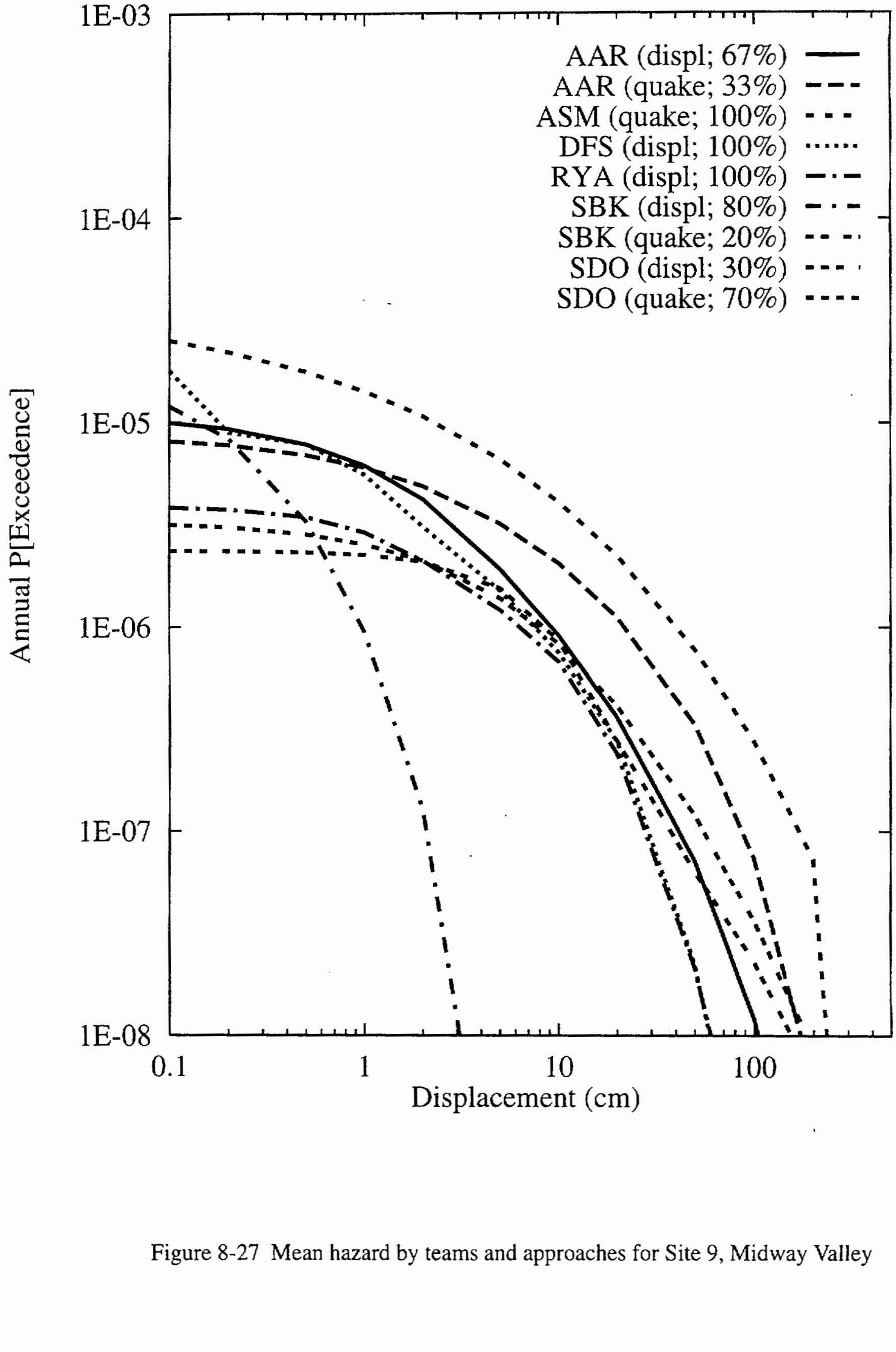

Figure 8-27 Mean hazard by teams and approaches for Site 9, Midway Valley

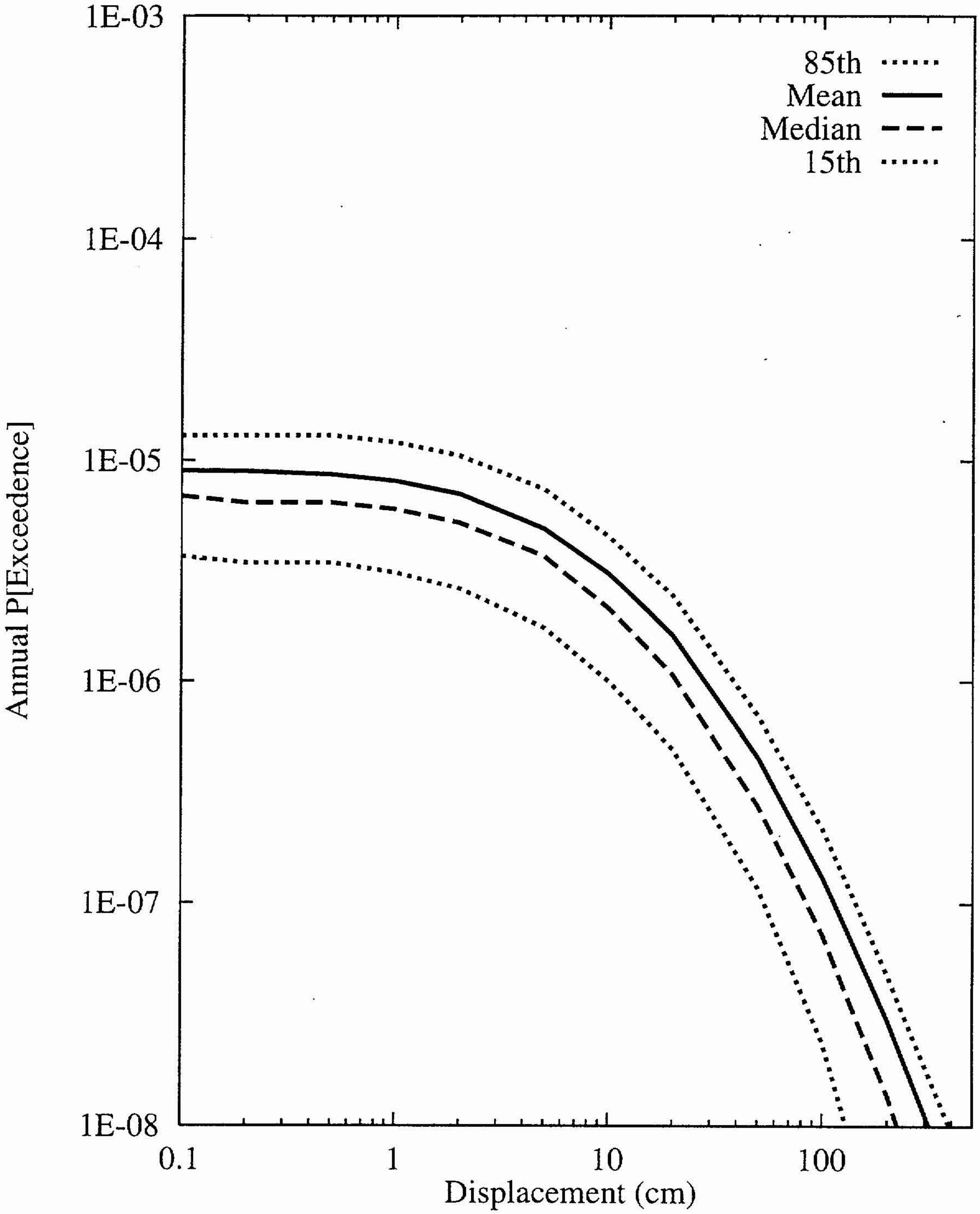

Figure 8-28 Summary hazard curves for Site 1: AAR team, earthquake approach

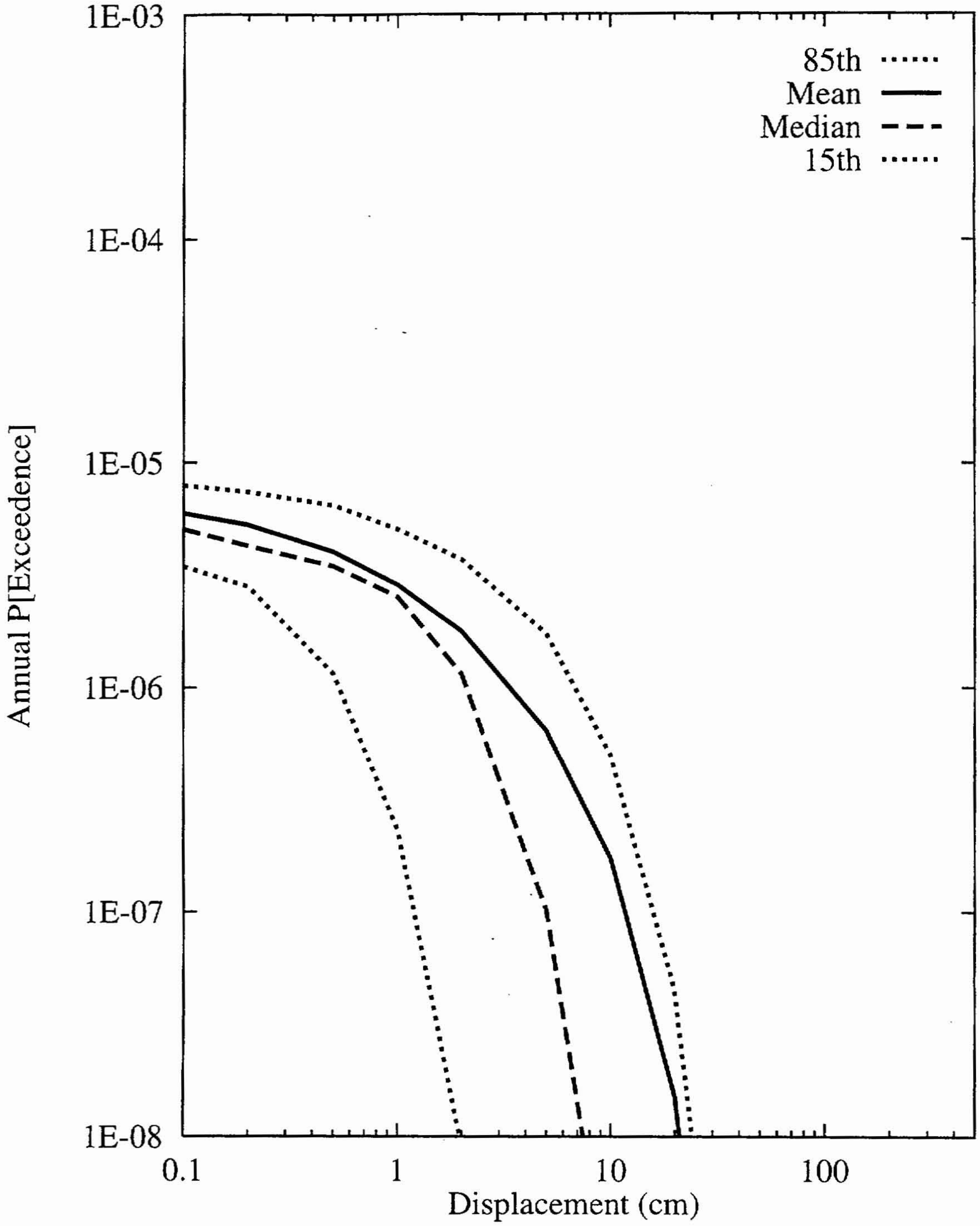

Figure 8-29 Summary hazard curves for Site 7a: AAR team, earthquake approach

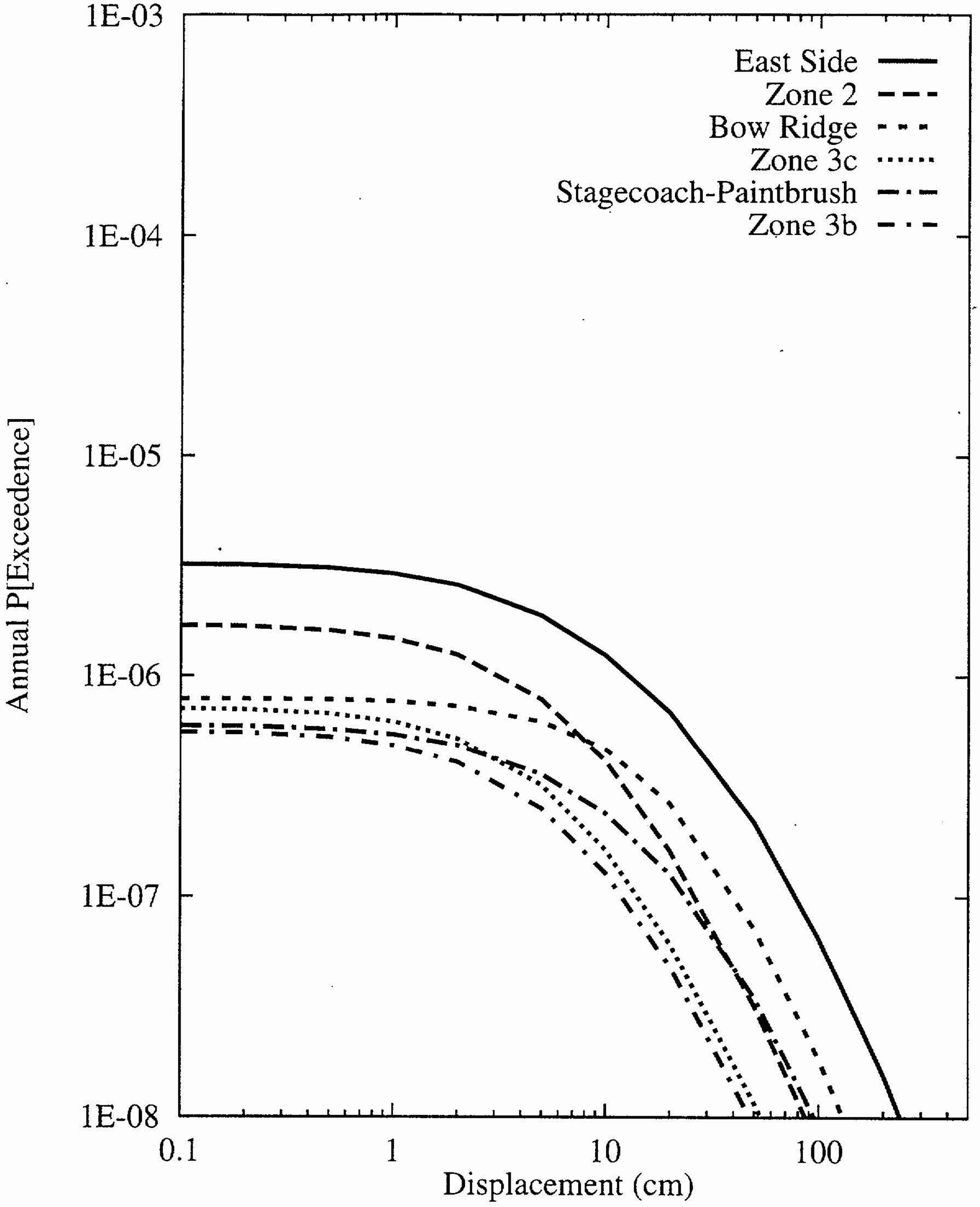

Figure 8-30 Mean hazard curves by source for Site 1: AAR team, earthquake approach

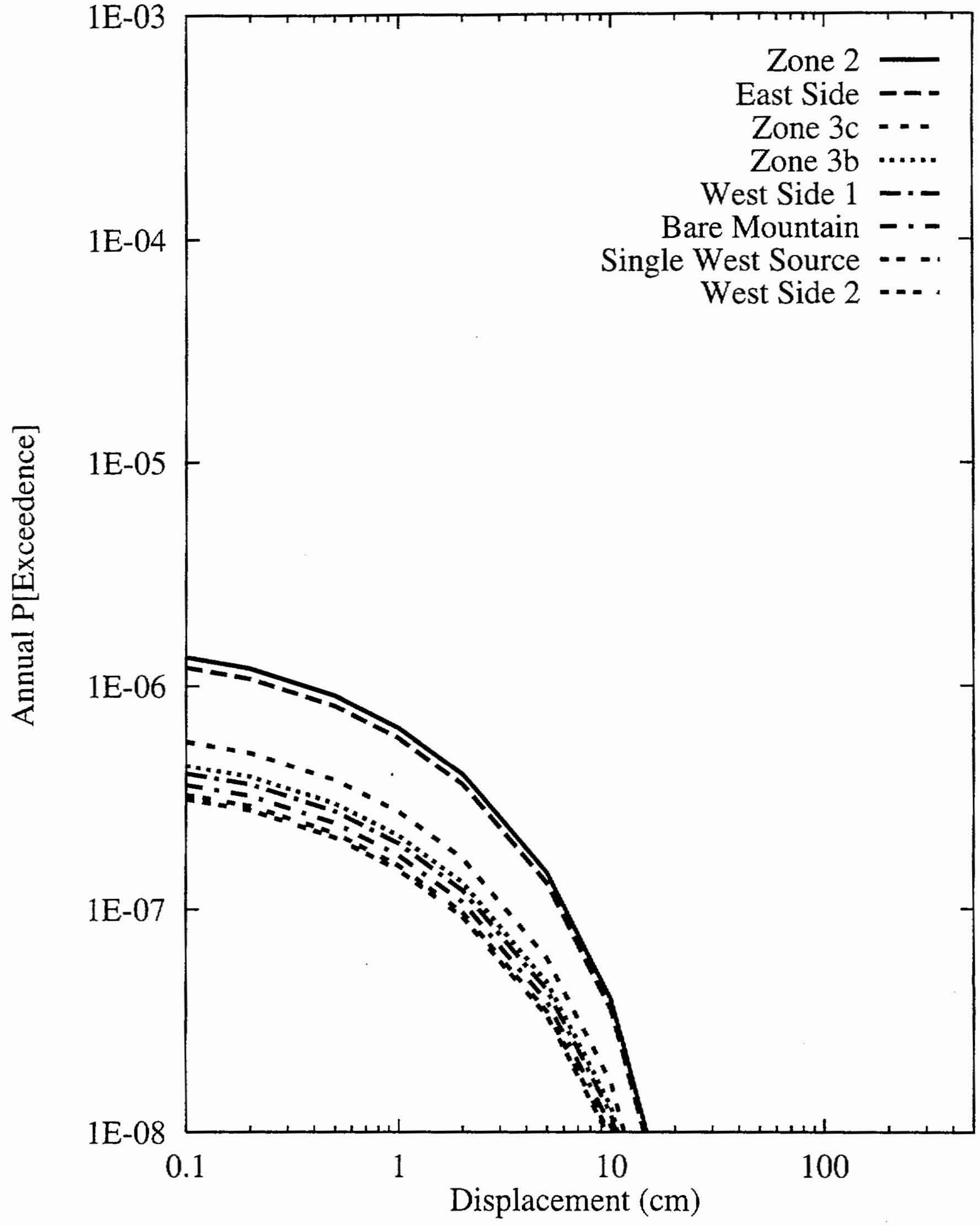

Figure 8-31 Mean hazard curves by source for Site 7a: AAR team, earthquake approach

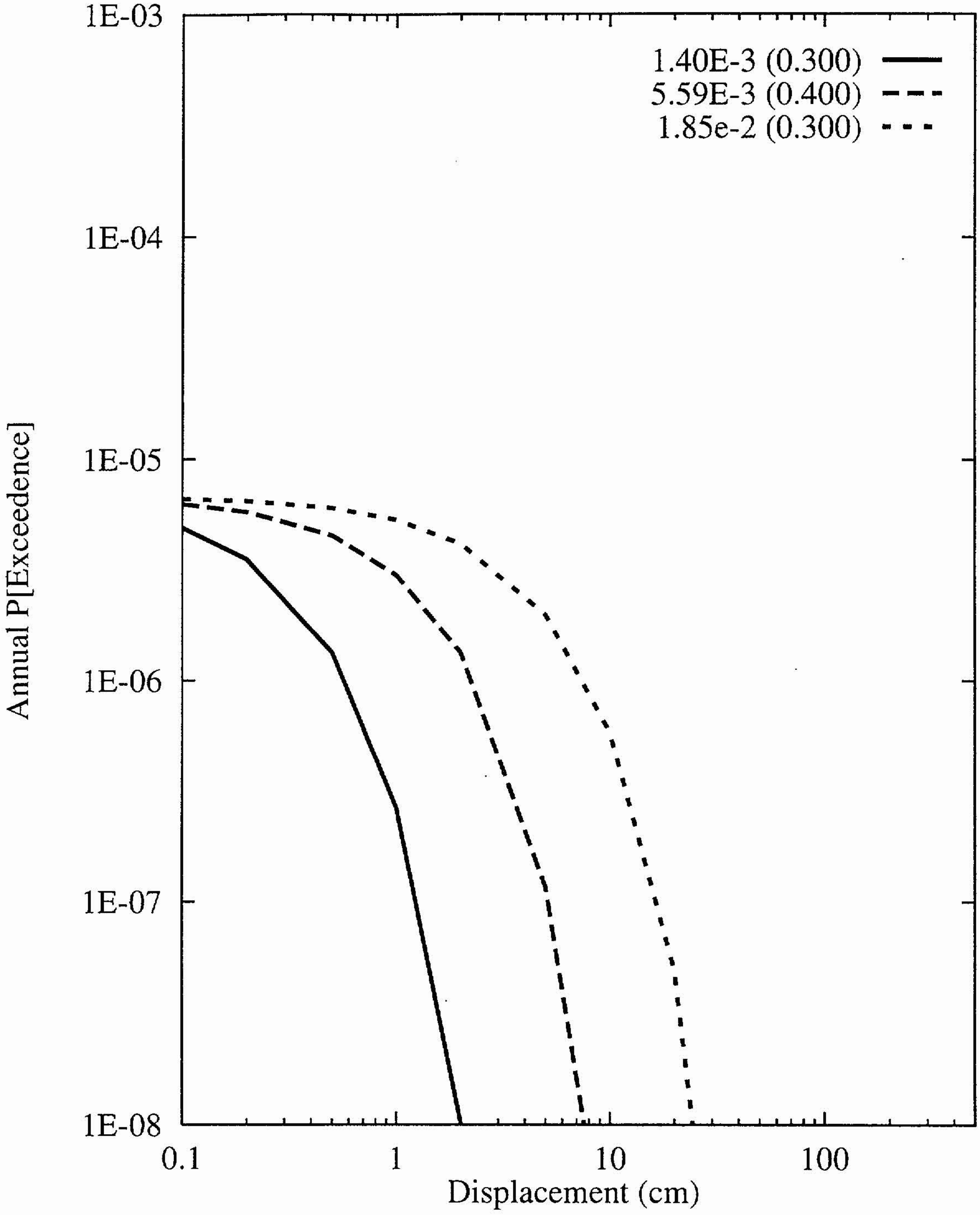

Figure 8-32 Sensitivity of displacement hazard for Site 1 to parameter beta: AAR team, earthquake approach

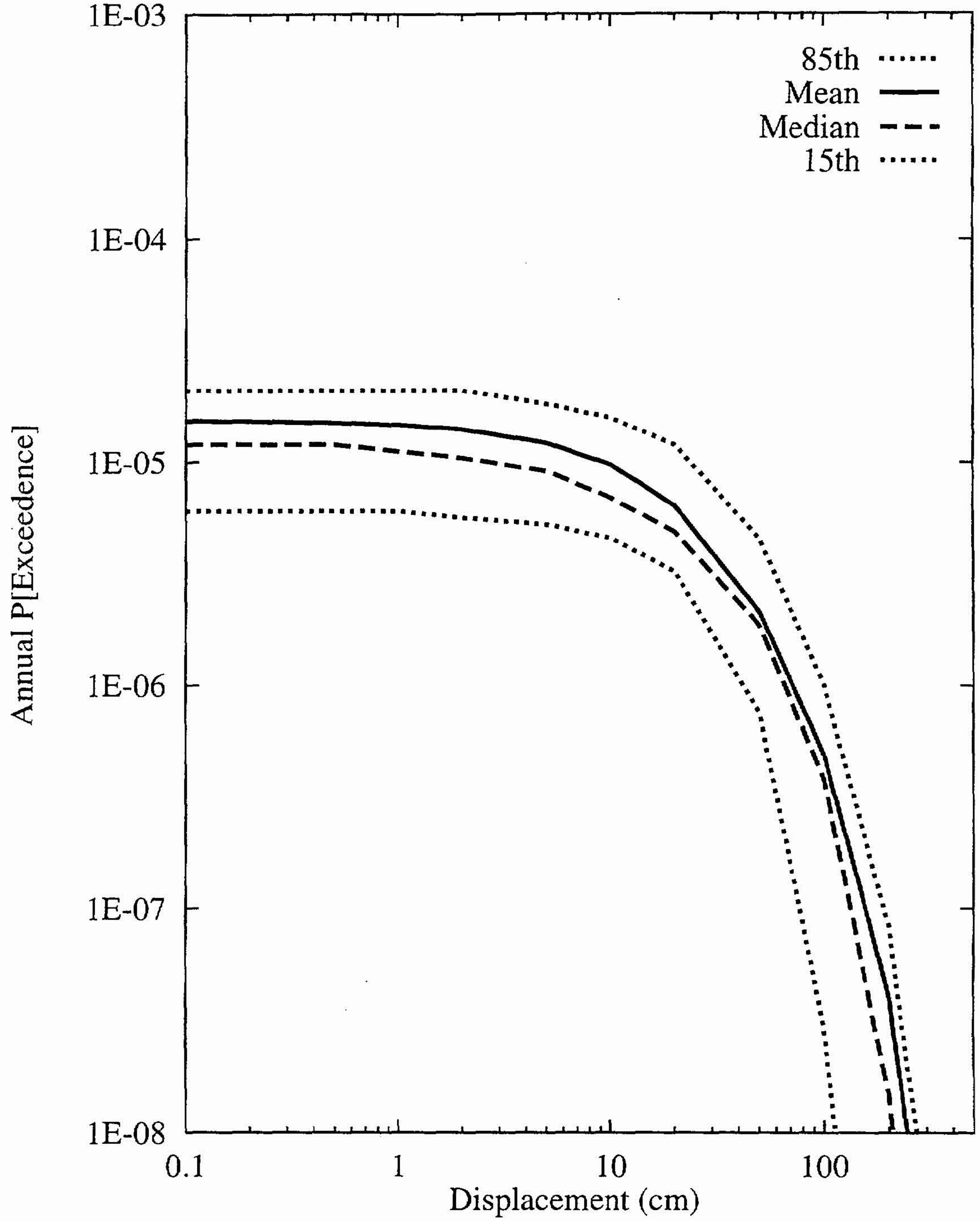

Figure 8-33 Summary hazard curves for Site 1: AAR team, displacement approach

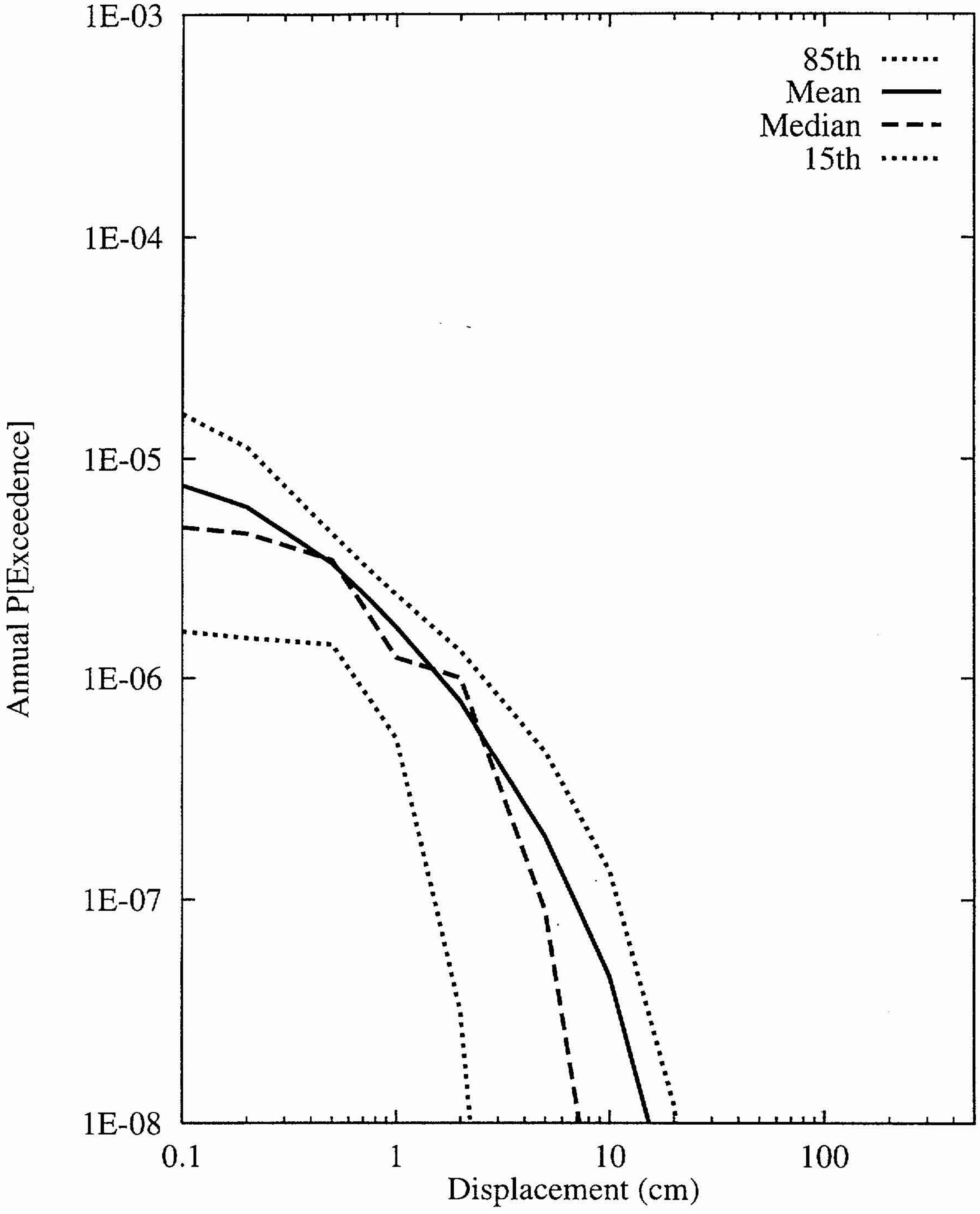

Figure 8-34 Summary hazard curves for Site 7a: AAR team, displacement approach

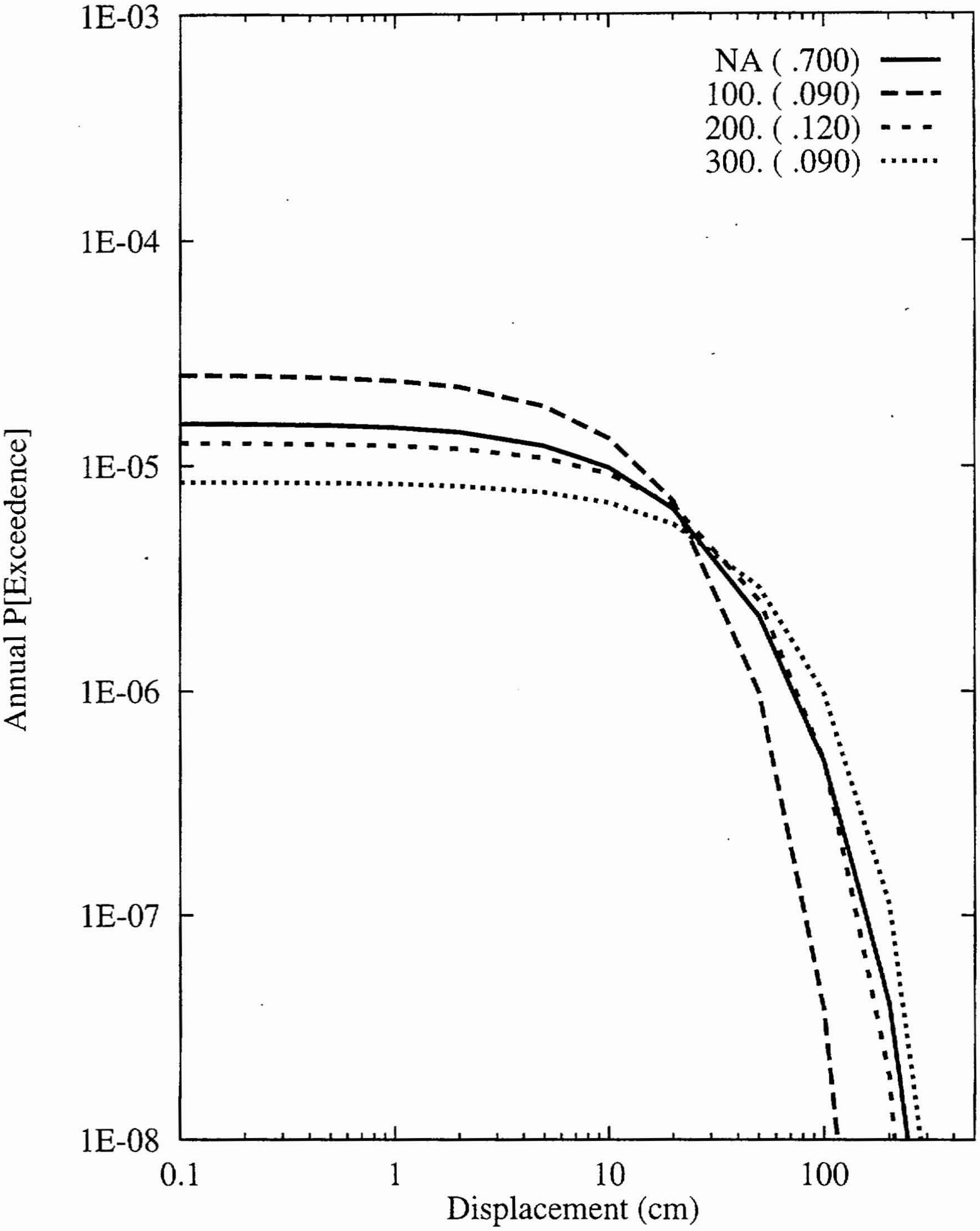

Figure 8-35 Sensitivity of displacement hazard for Site 1 to cumulative displacement: AAR team, displacement approach

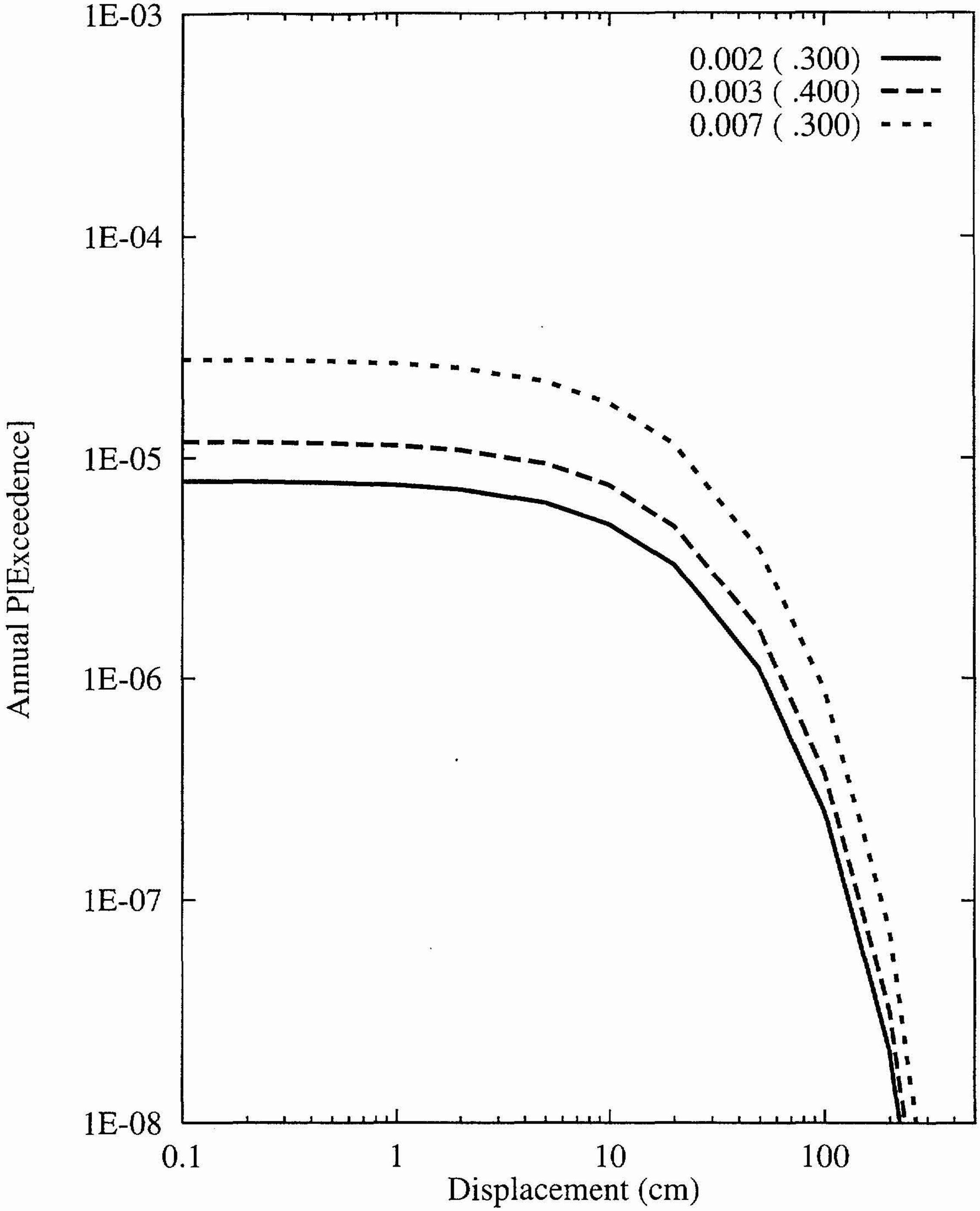

Figure 8-36 Sensitivity of displacement hazard for Site 1 to slip rate:
AAR team, displacement approach

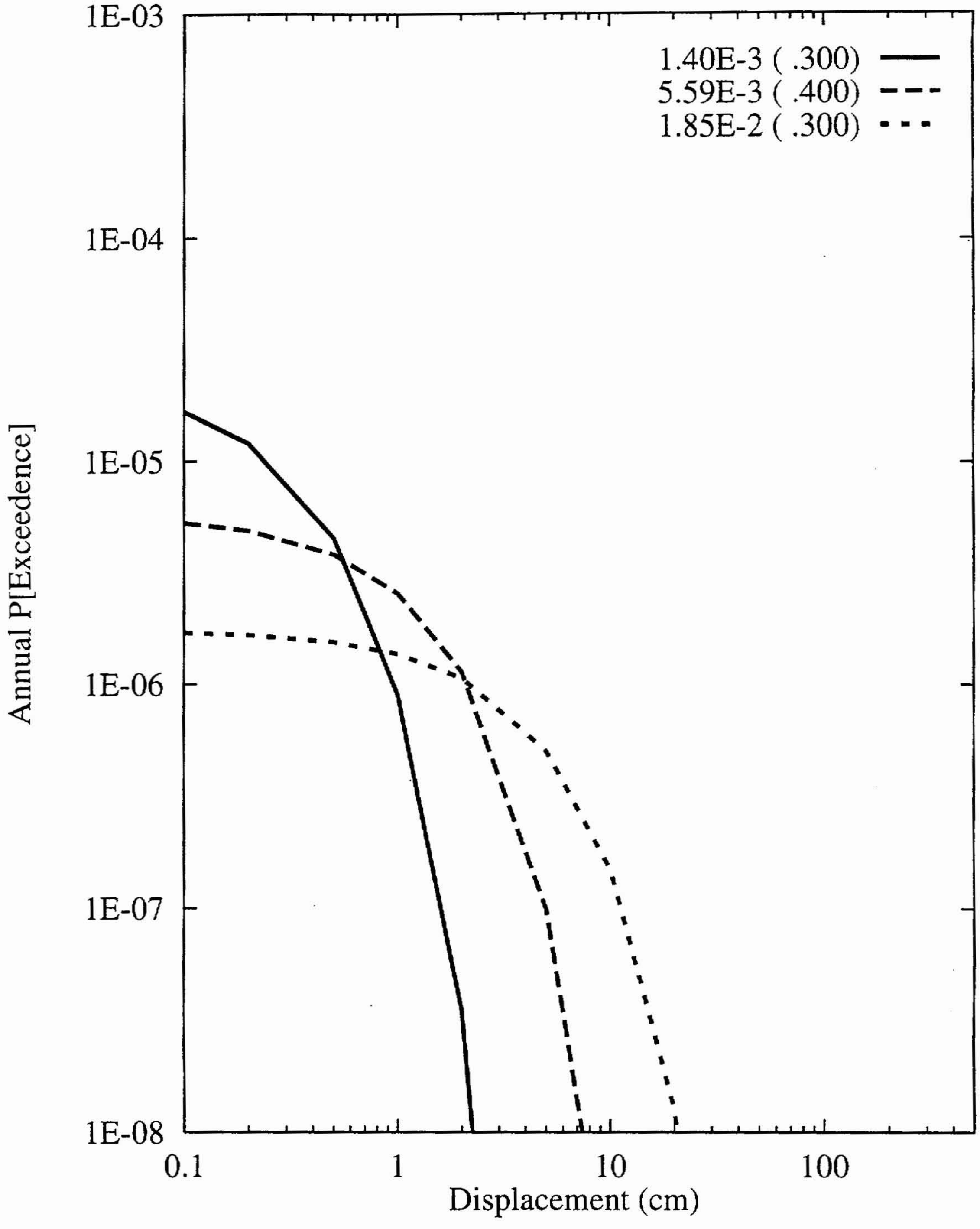

Figure 8-37 Sensitivity of displacement hazard for Site 7a to parameter beta: AAR team, displacement approach

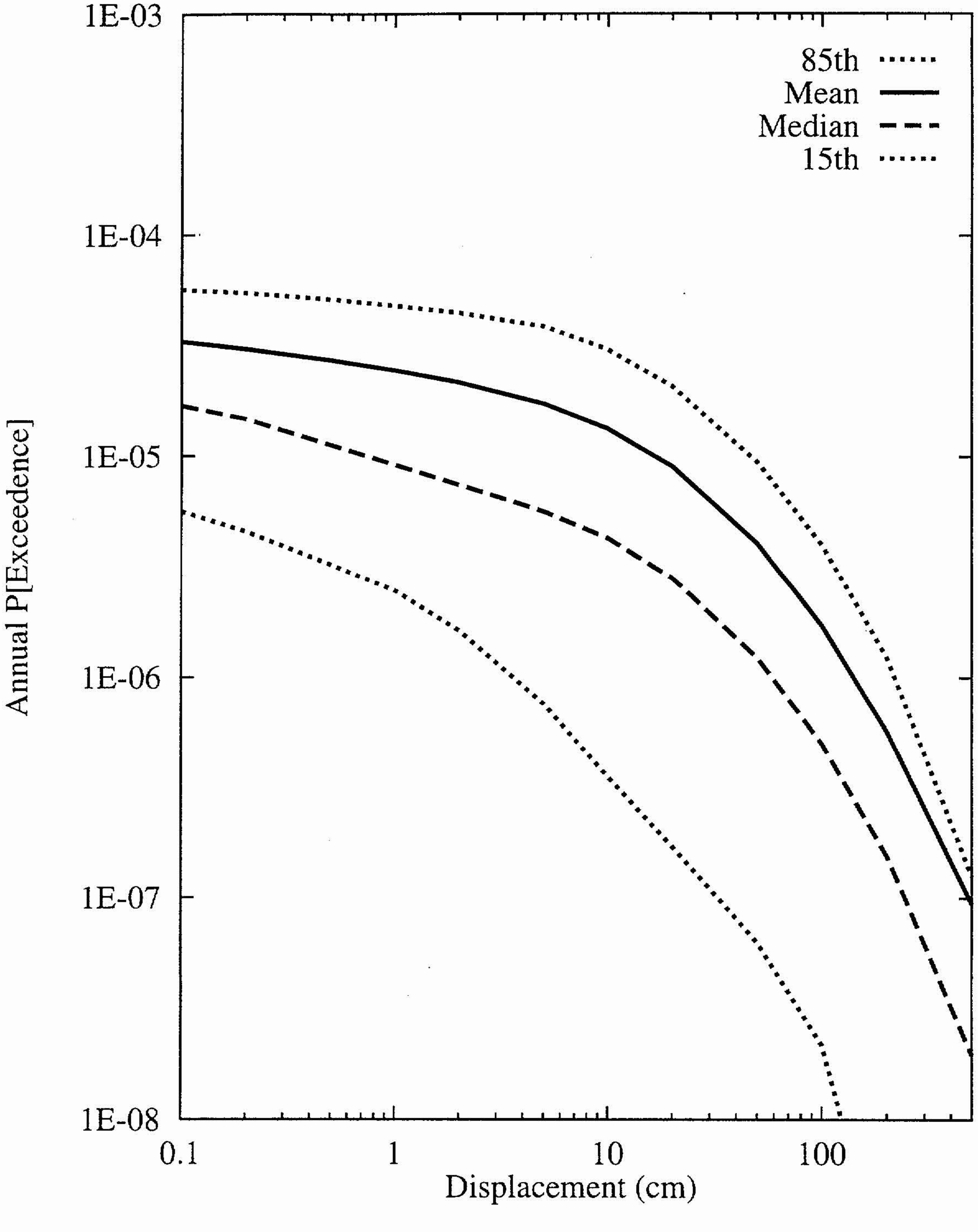

Figure 8-38 Summary hazard curves for Site 1: ASM team, earthquake approach

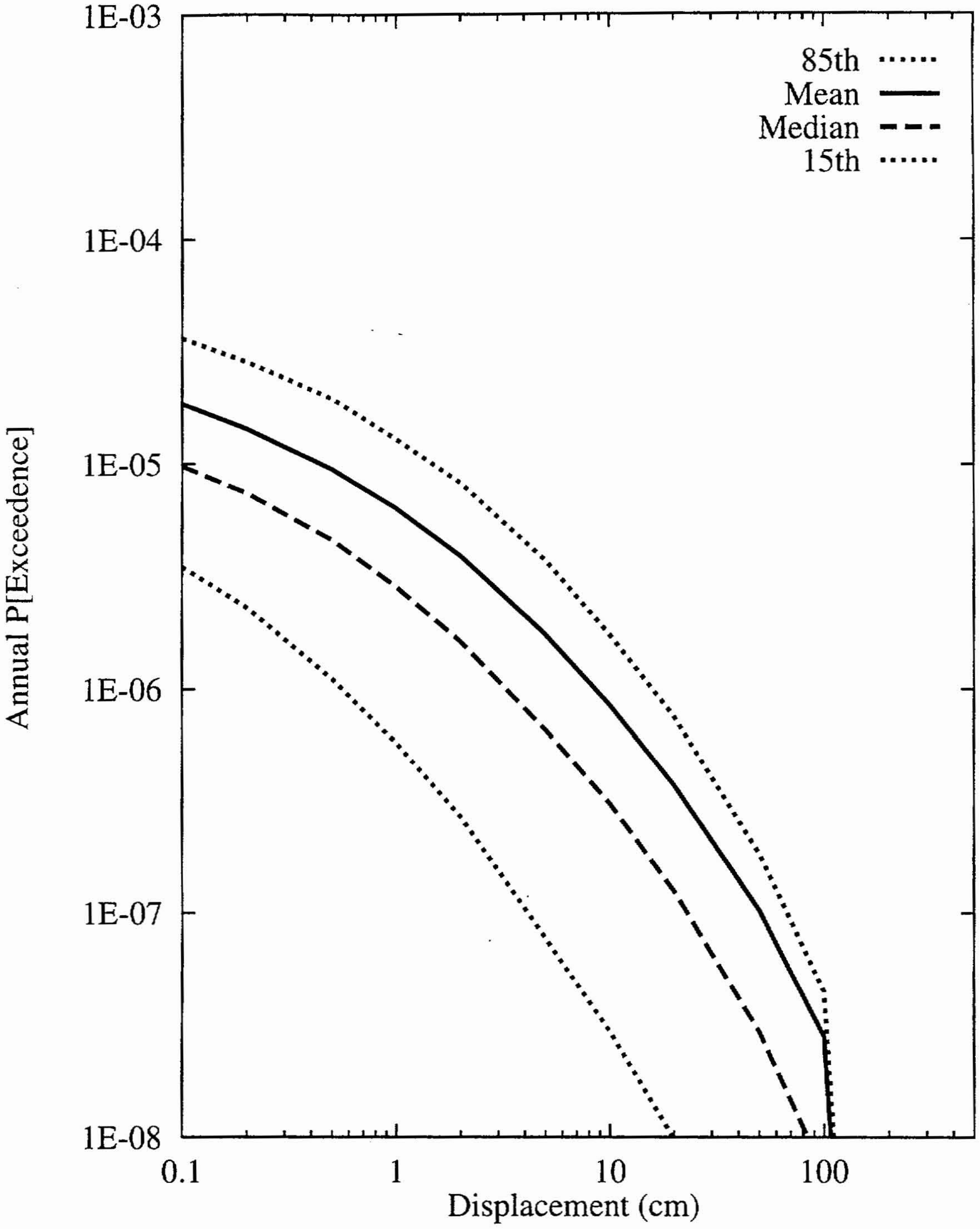

Figure 8-39 Summary hazard curves for Site 7a: ASM team, earthquake approach

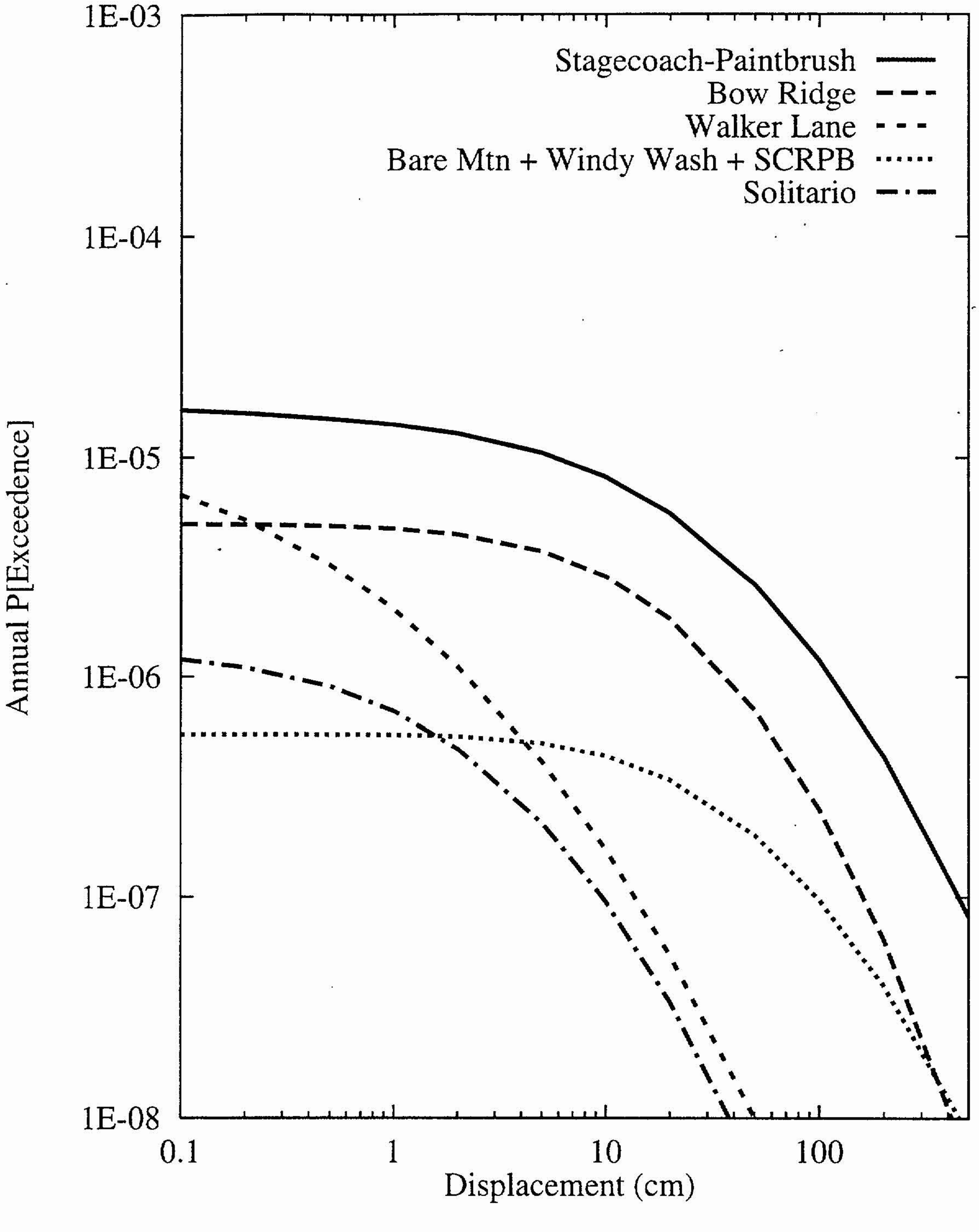

Figure 8-40 Mean hazard curves by source for Site 1: ASM team, earthquake approach

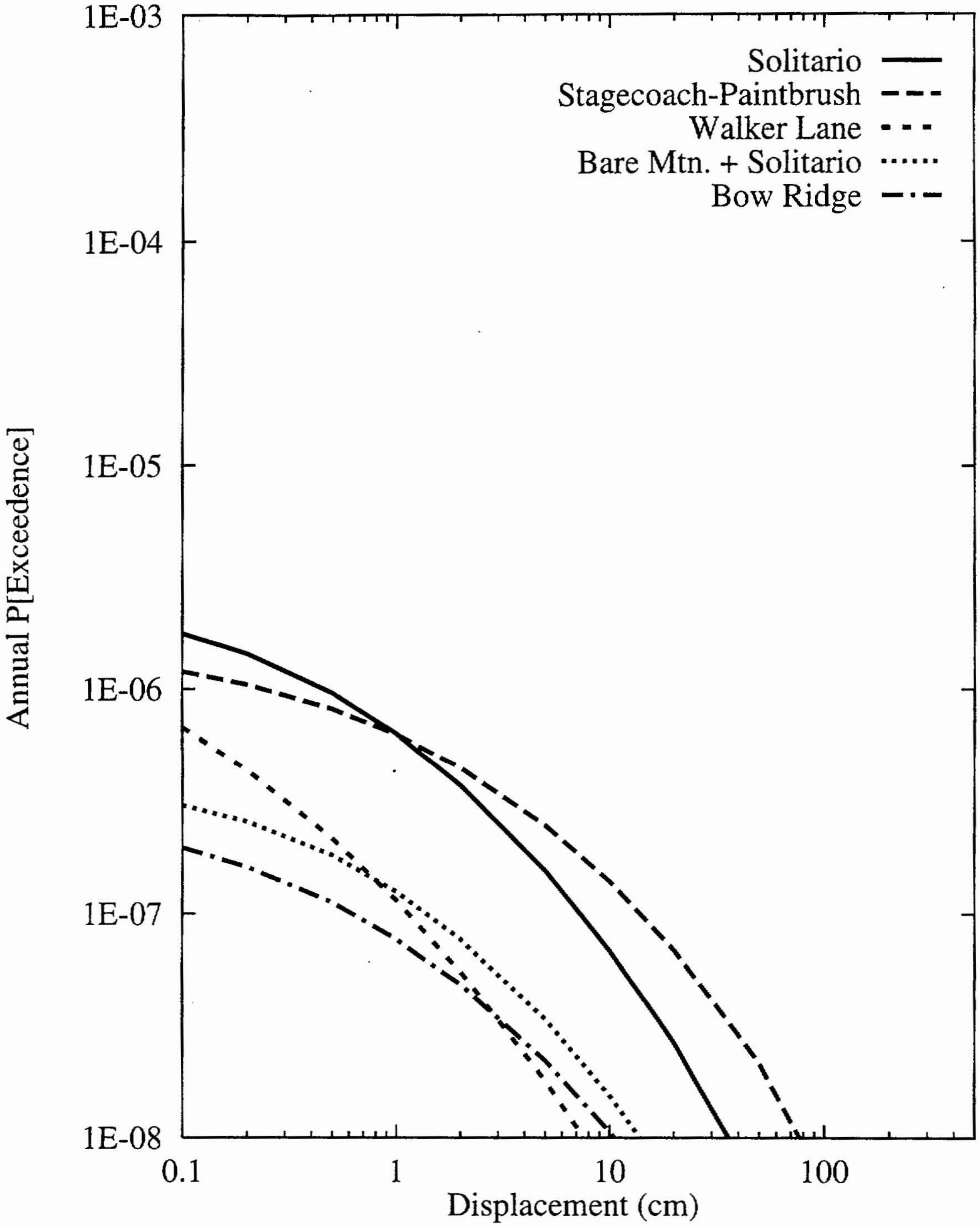

Figure 8-41 Mean hazard curves by source for Site 7a: ASM team, earthquake approach

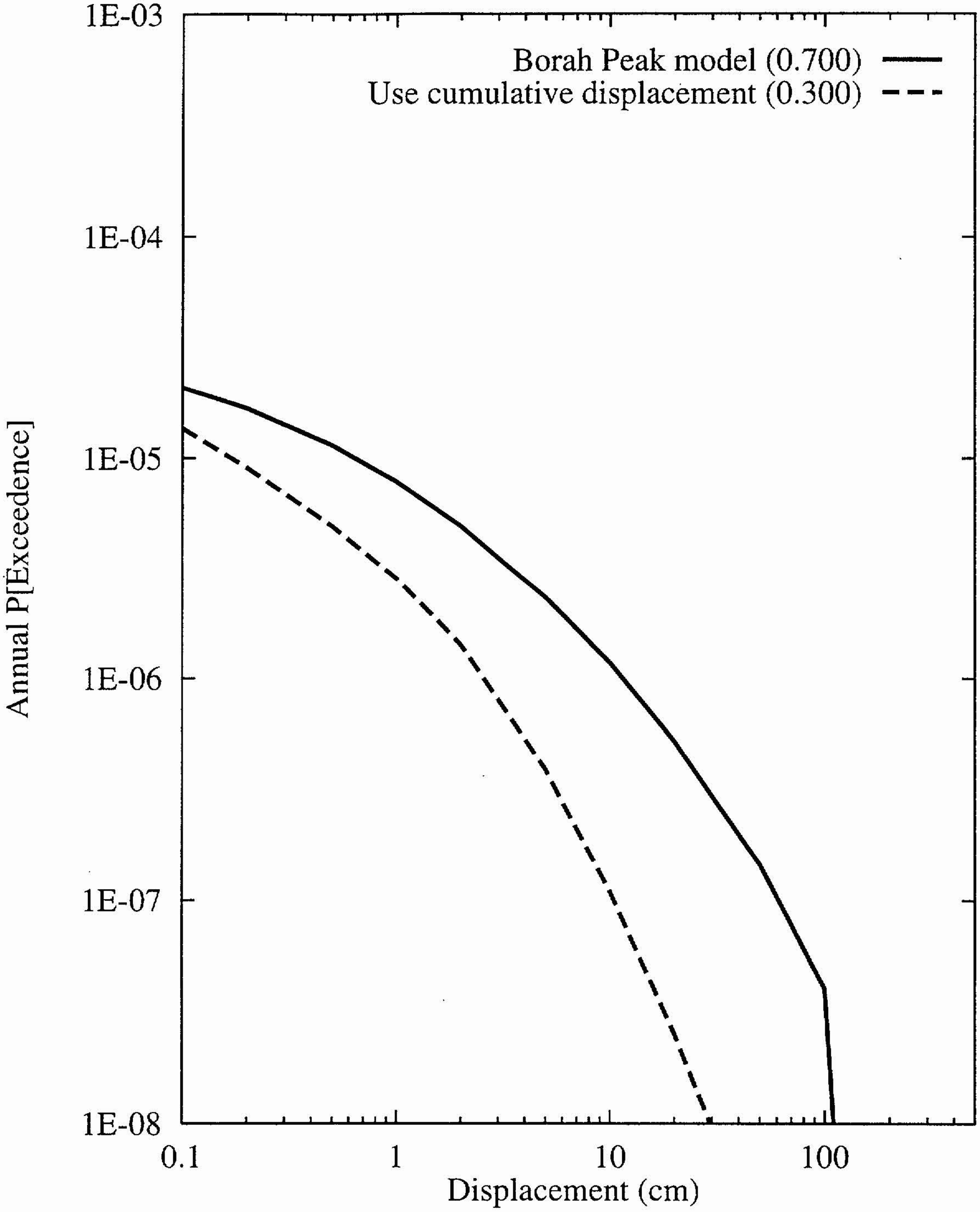

Figure 8-42 Sensitivity of displacement hazard for Site 7a to scaling of principal to distributed faulting: ASM team, earthquake approach

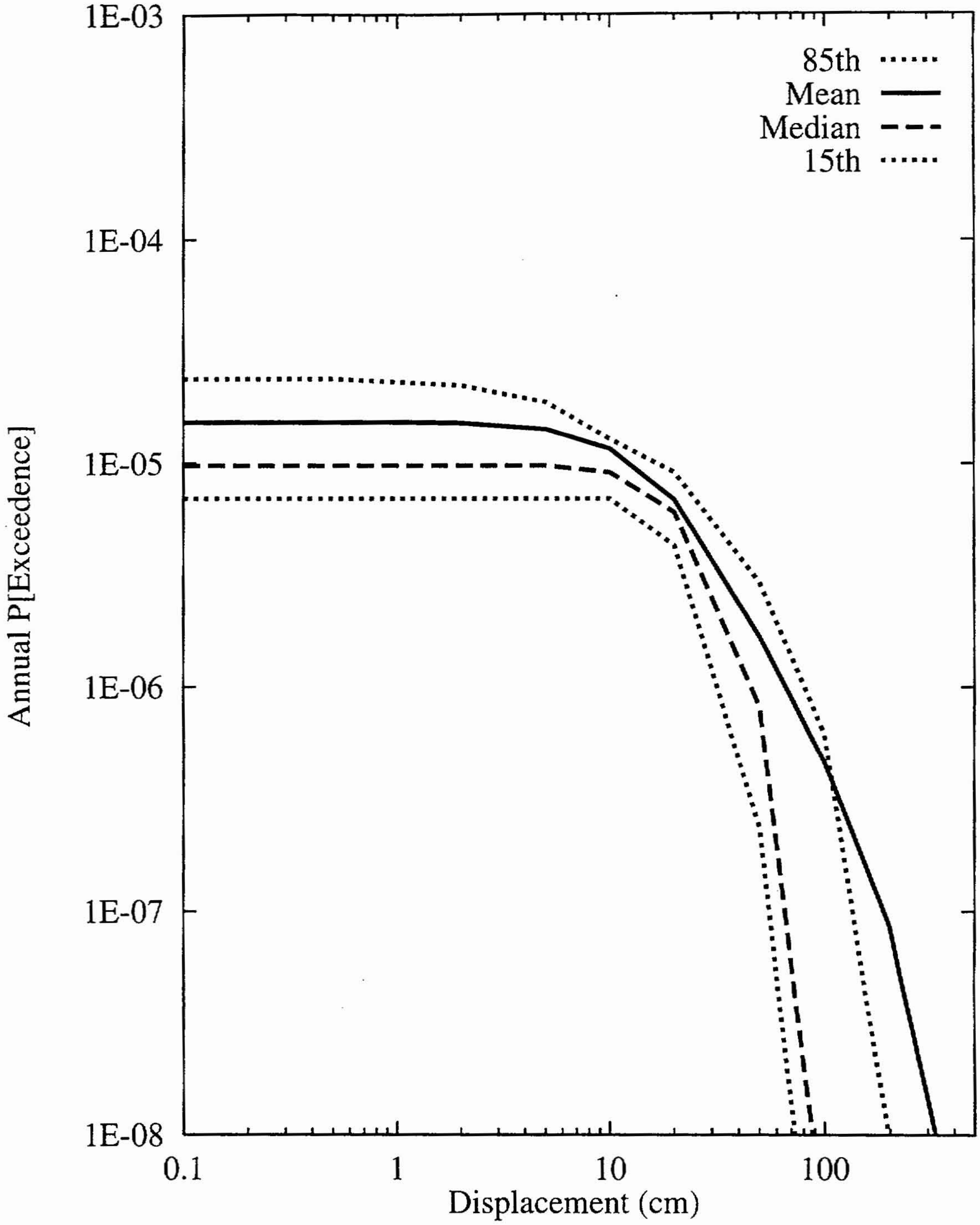

Figure 8-43 Summary hazard curves for Site 1: DFS team, displacement approach

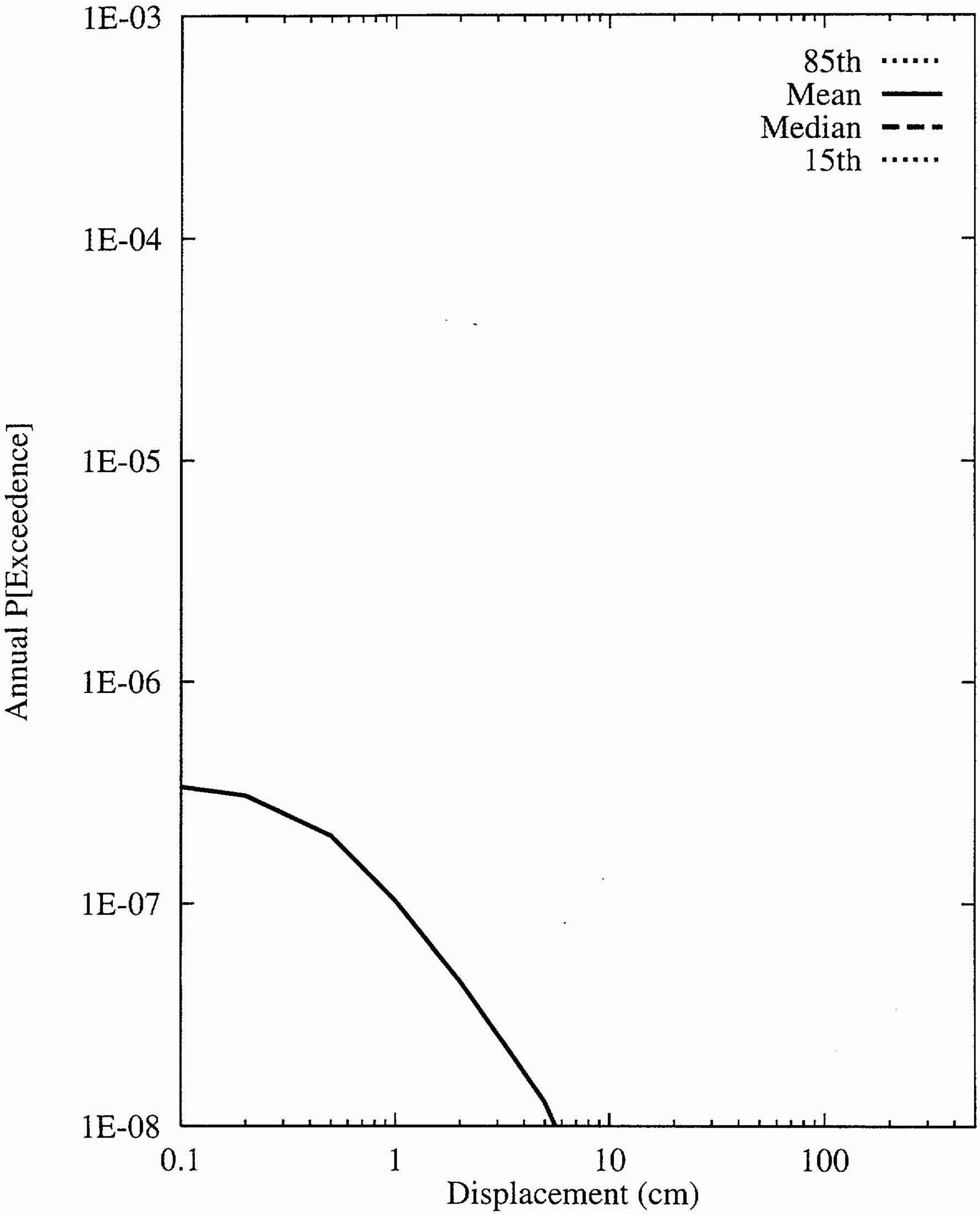

Figure 8-44 Summary hazard curves for Site 7a: DFS team, displacement approach

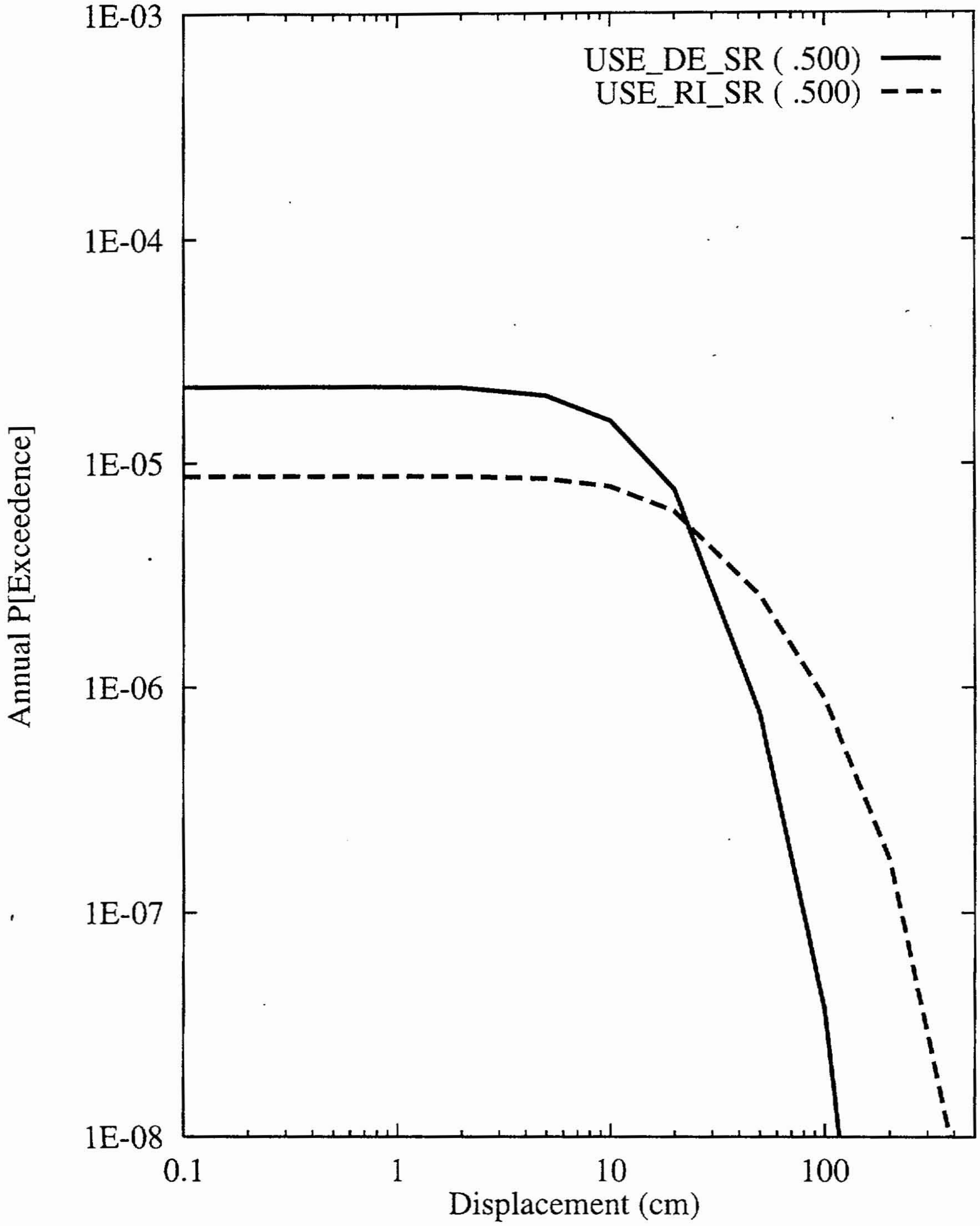

Figure 8-45 Sensitivity of displacement hazard for Site 1 to calculation option: DFS team, displacement approach

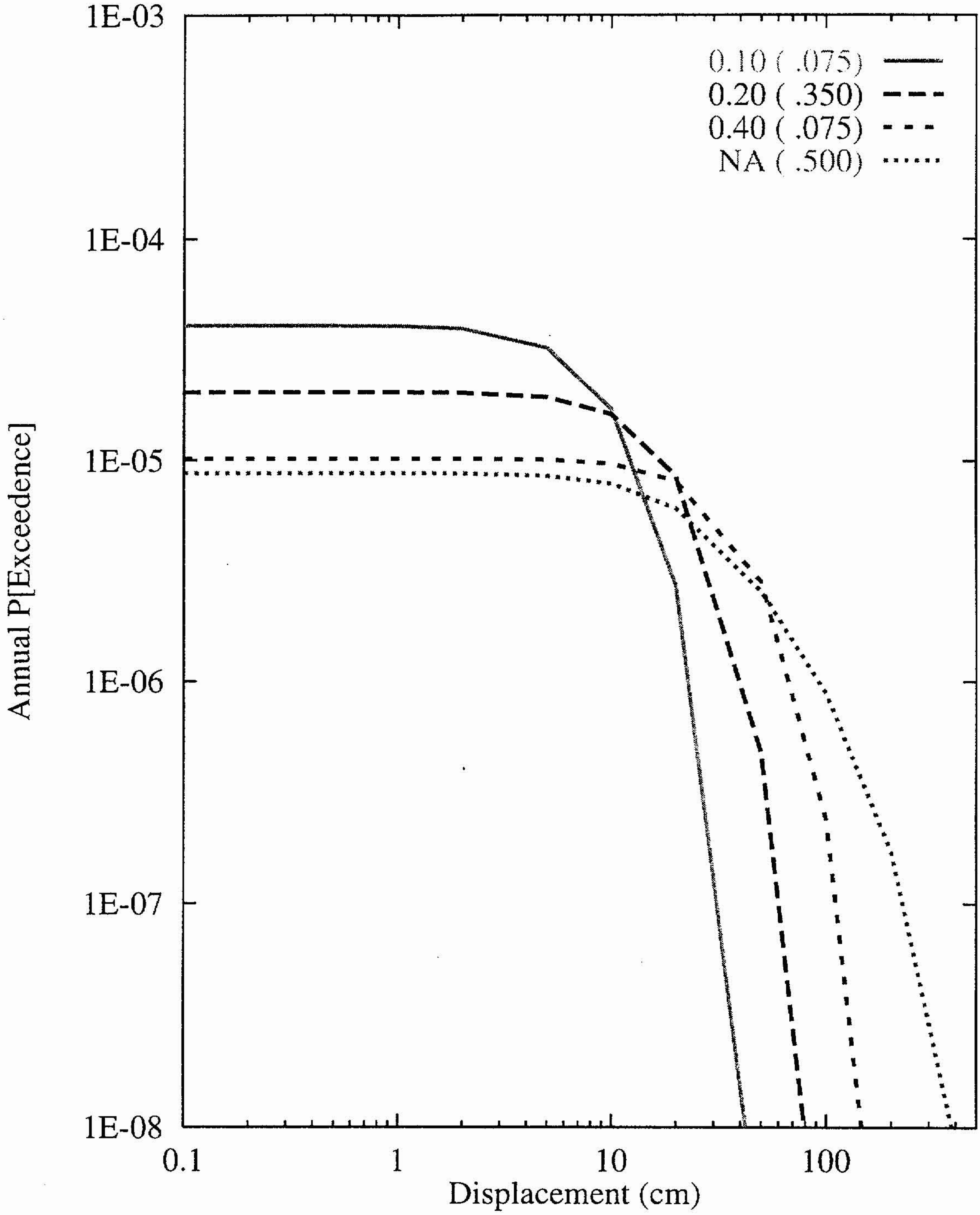

Figure 8-46 Sensitivity of displacement hazard for Site 1 to average displacement per event (m): DFS team, displacement approach

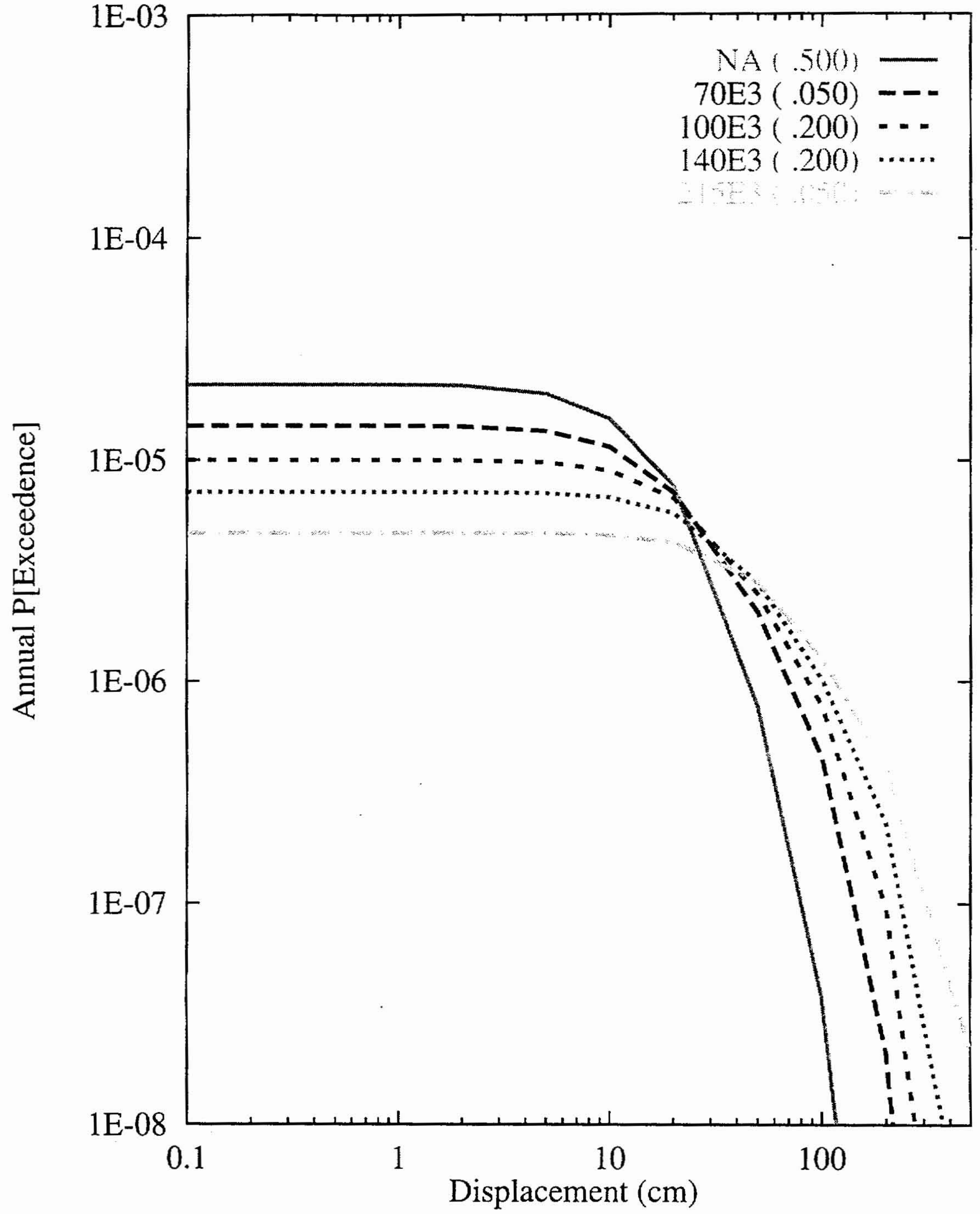

Figure 8-47 Sensitivity of displacement hazard for Site 1 to recurrence interval: DFS team, displacement approach

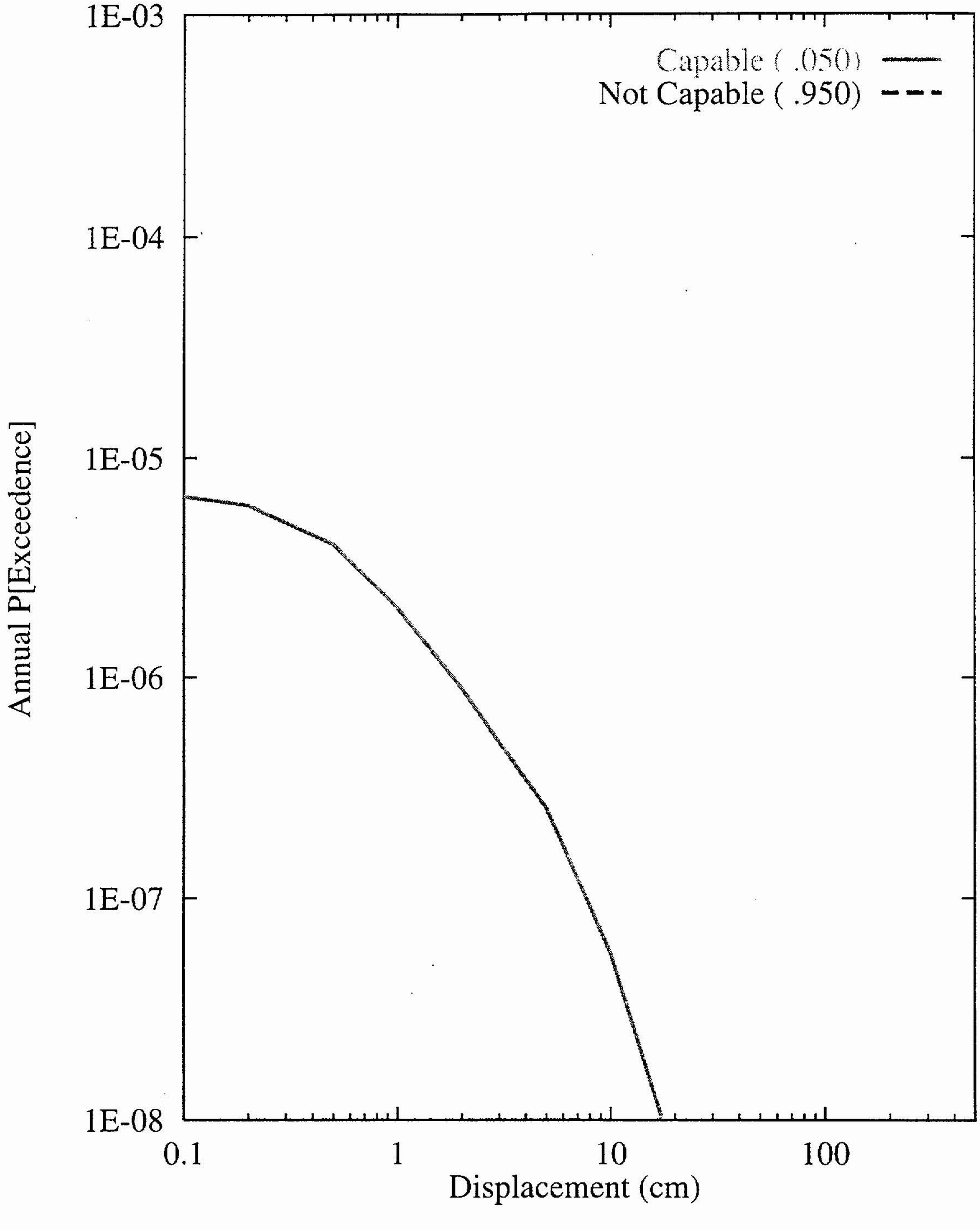

Figure 8-48 Sensitivity of displacement hazard for Site 7a to capability for fault displacement: DFS team, displacement approach

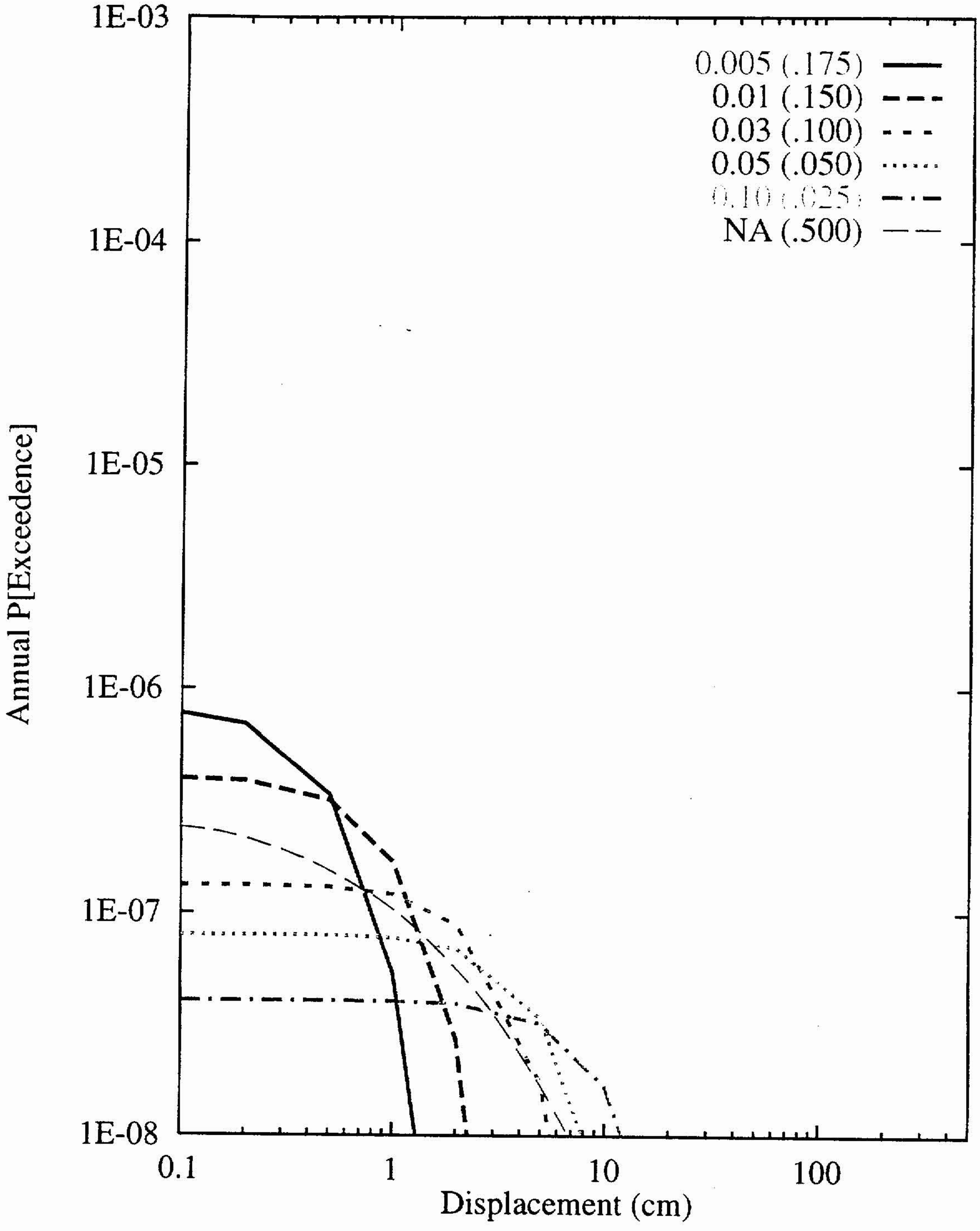

Figure 8-49 Sensitivity of displacement hazard for Site 7a to average displacement per event (m): DFS team, desplacement approach

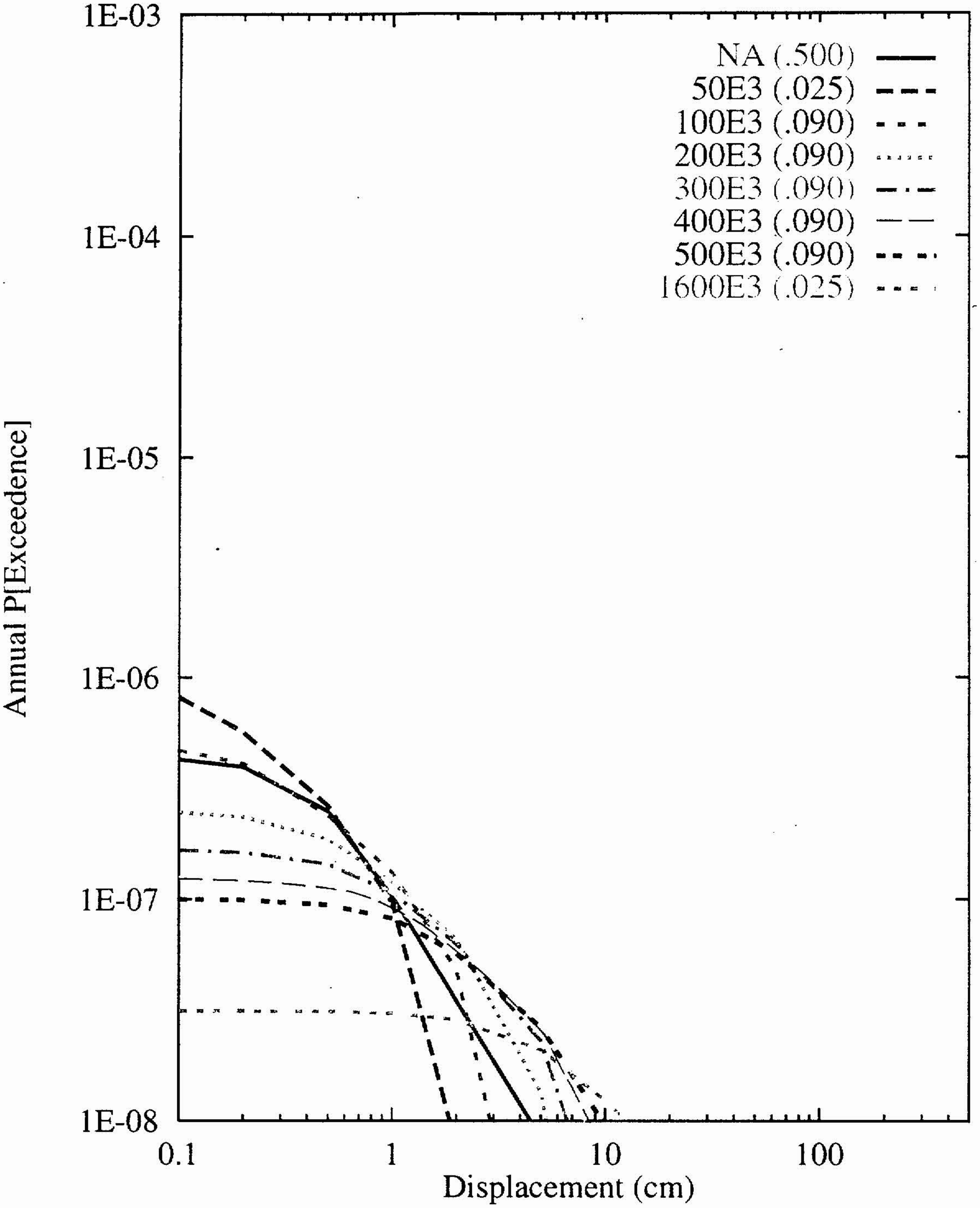

Figure 8-50 Sensitivity of displacement hazard for Site 7a to recurrence interval: DFS team, displacement approach

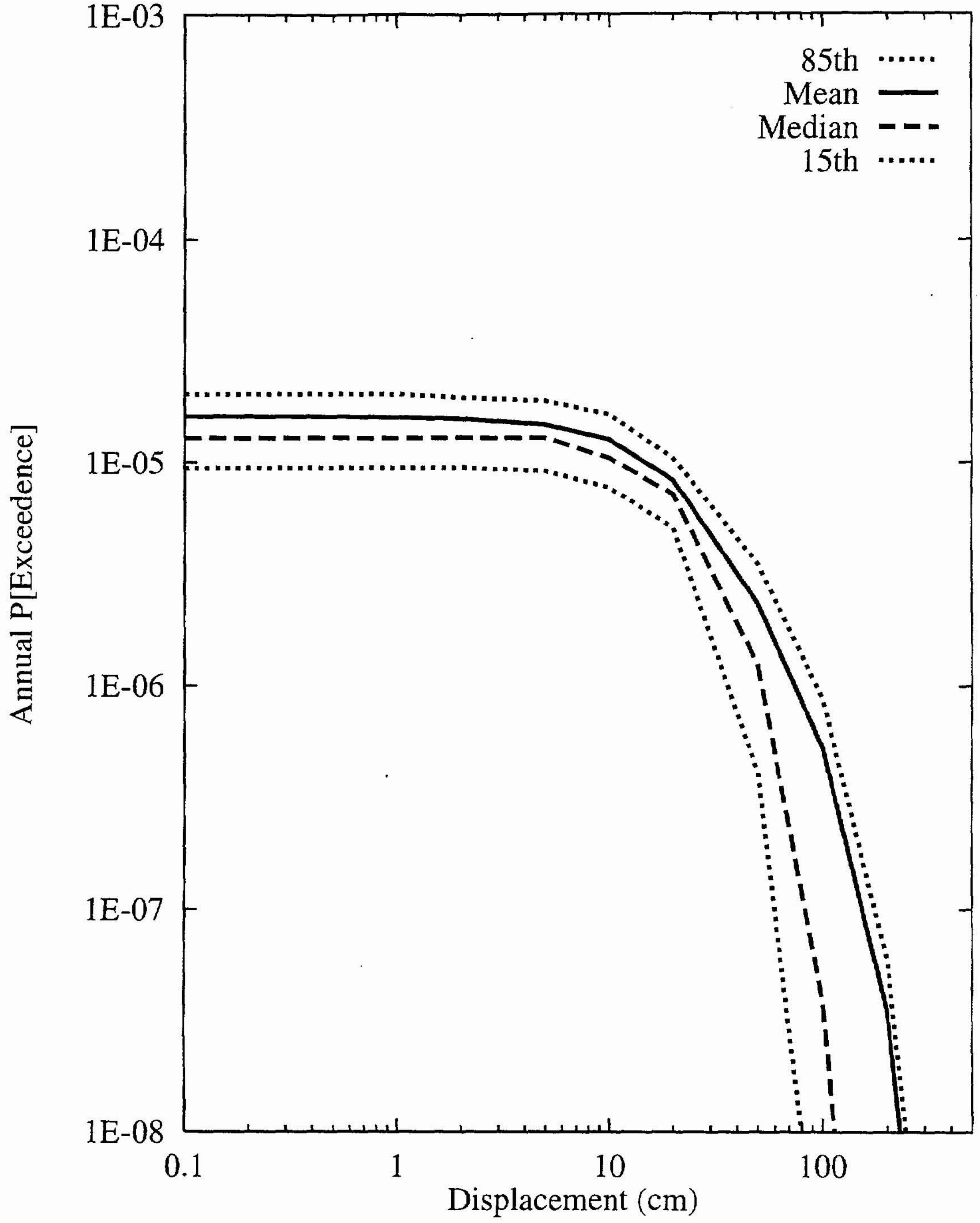

Figure 8-51 Summary hazard curves for Site 1: RYA team, displacement approach

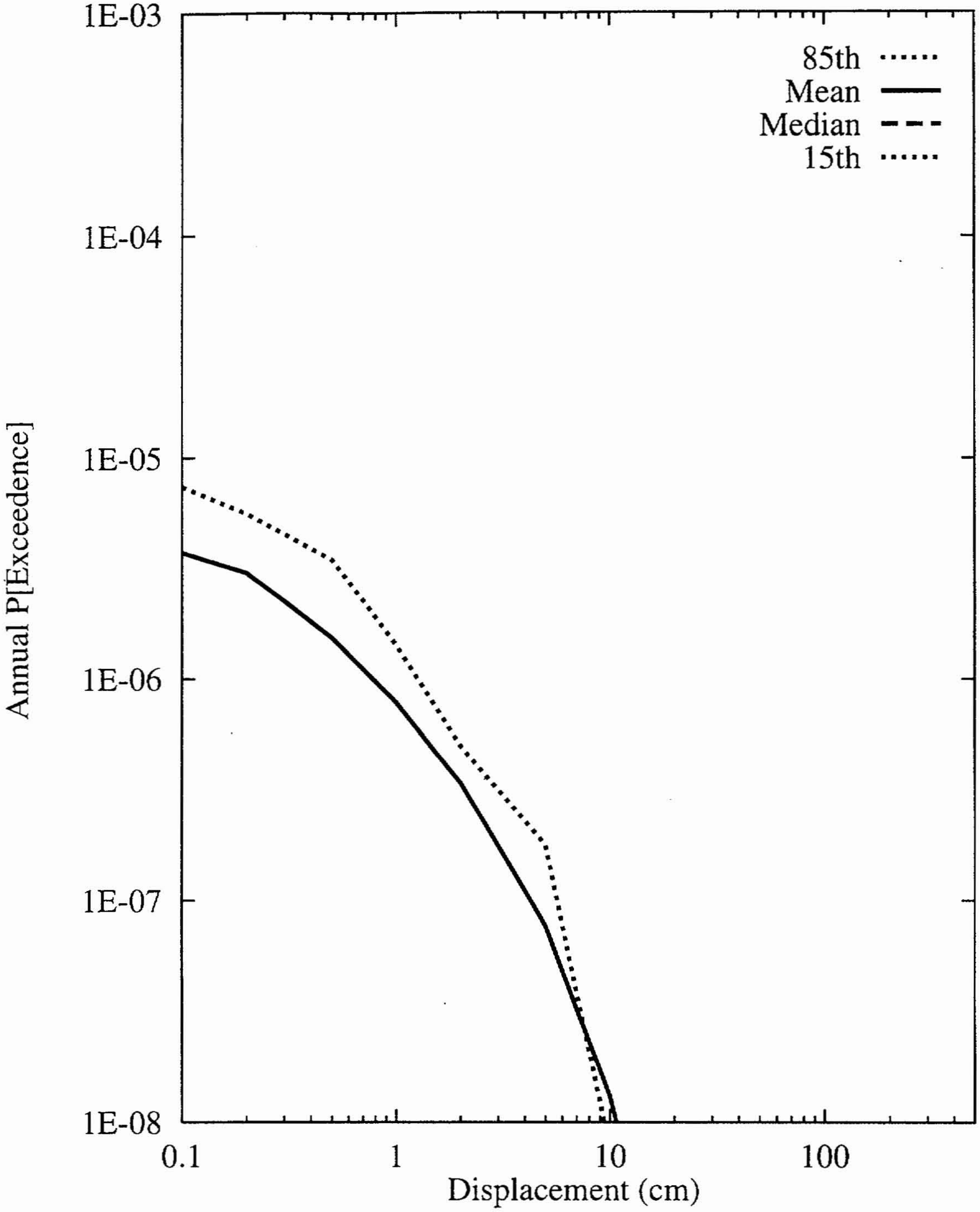

Figure 8-52 Summary hazard curves for Site 7a: RYA team, displacement approach

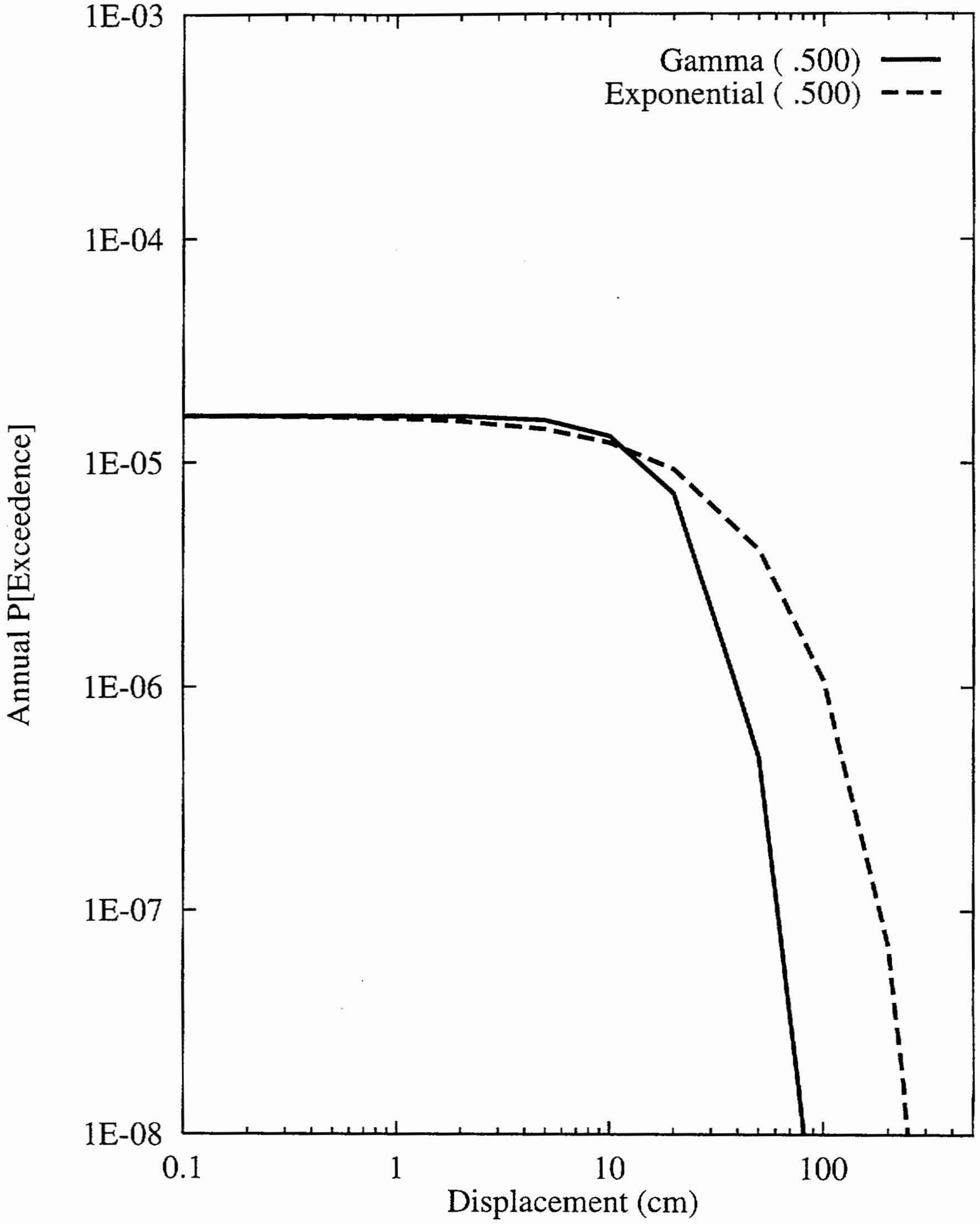

Figure 8-53 Sensitivity of displacement hazard for Site 1 to distribution shape: RYA team, displacement approach

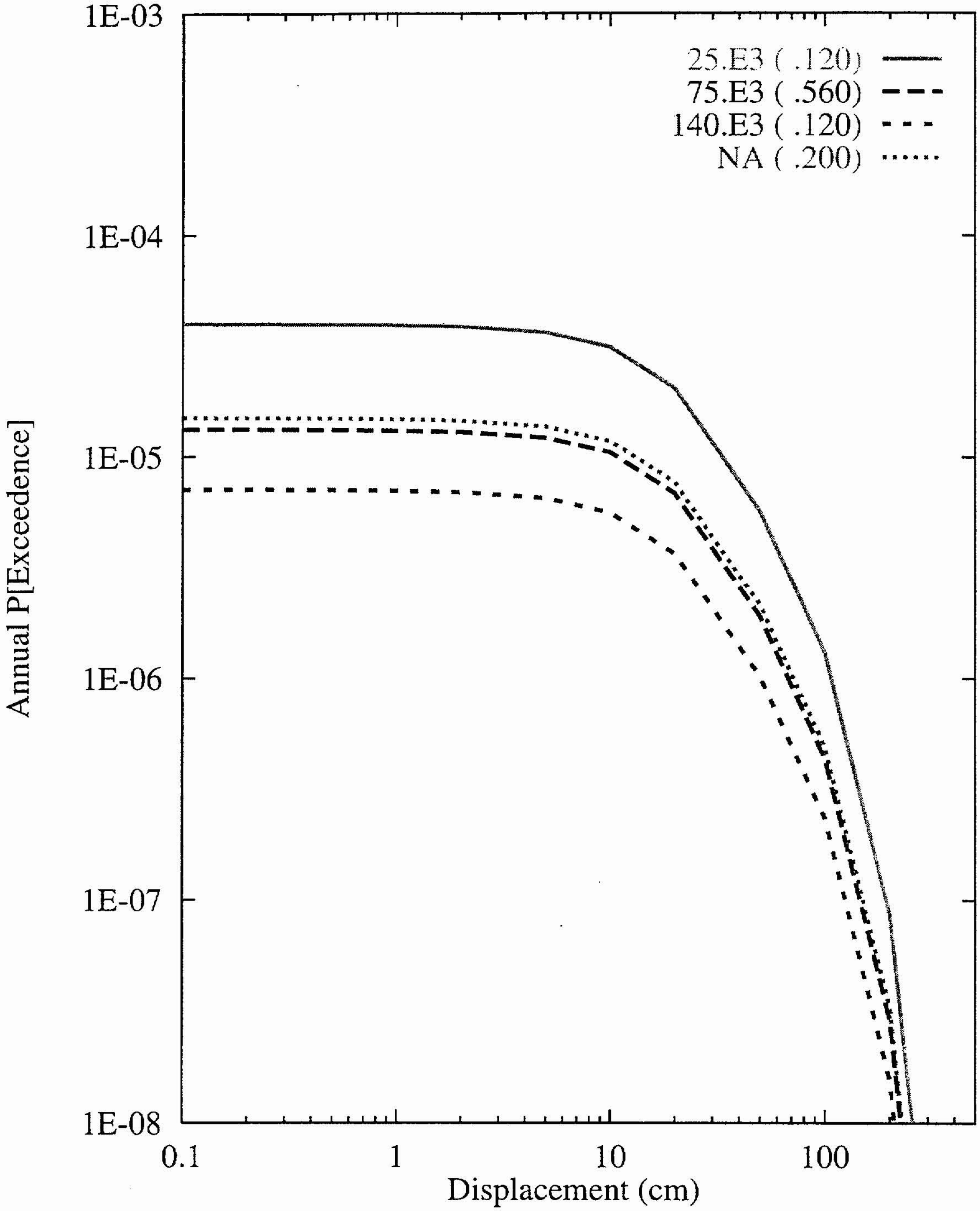

Figure 8-54 Sensitivity of displacement hazard for Site 1 to recurrence interval: RYA team, displacement approach

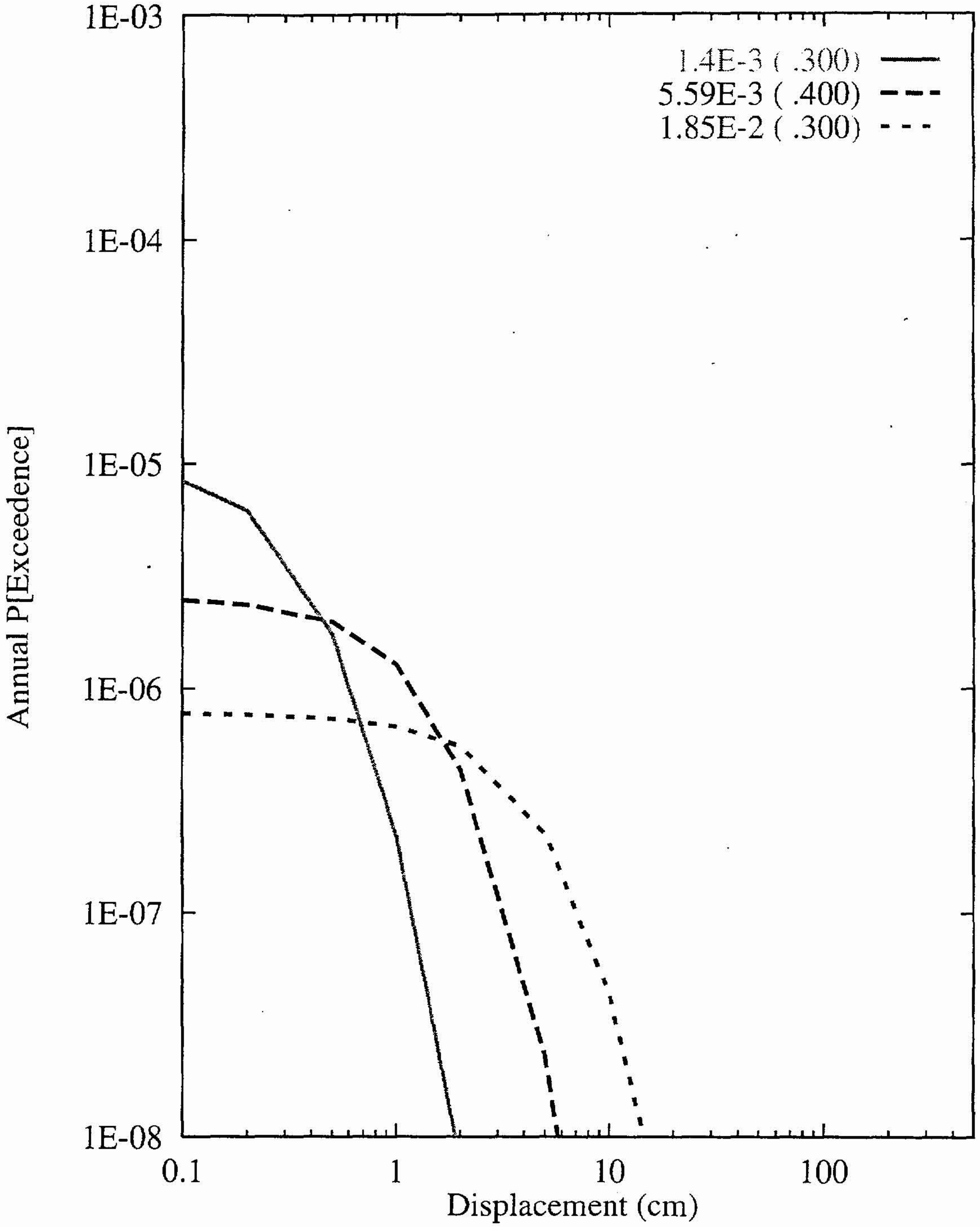

Figure 8-55 Sensitivity of displacement hazard for Site 7a to parameter beta: RYA team, displacement approach

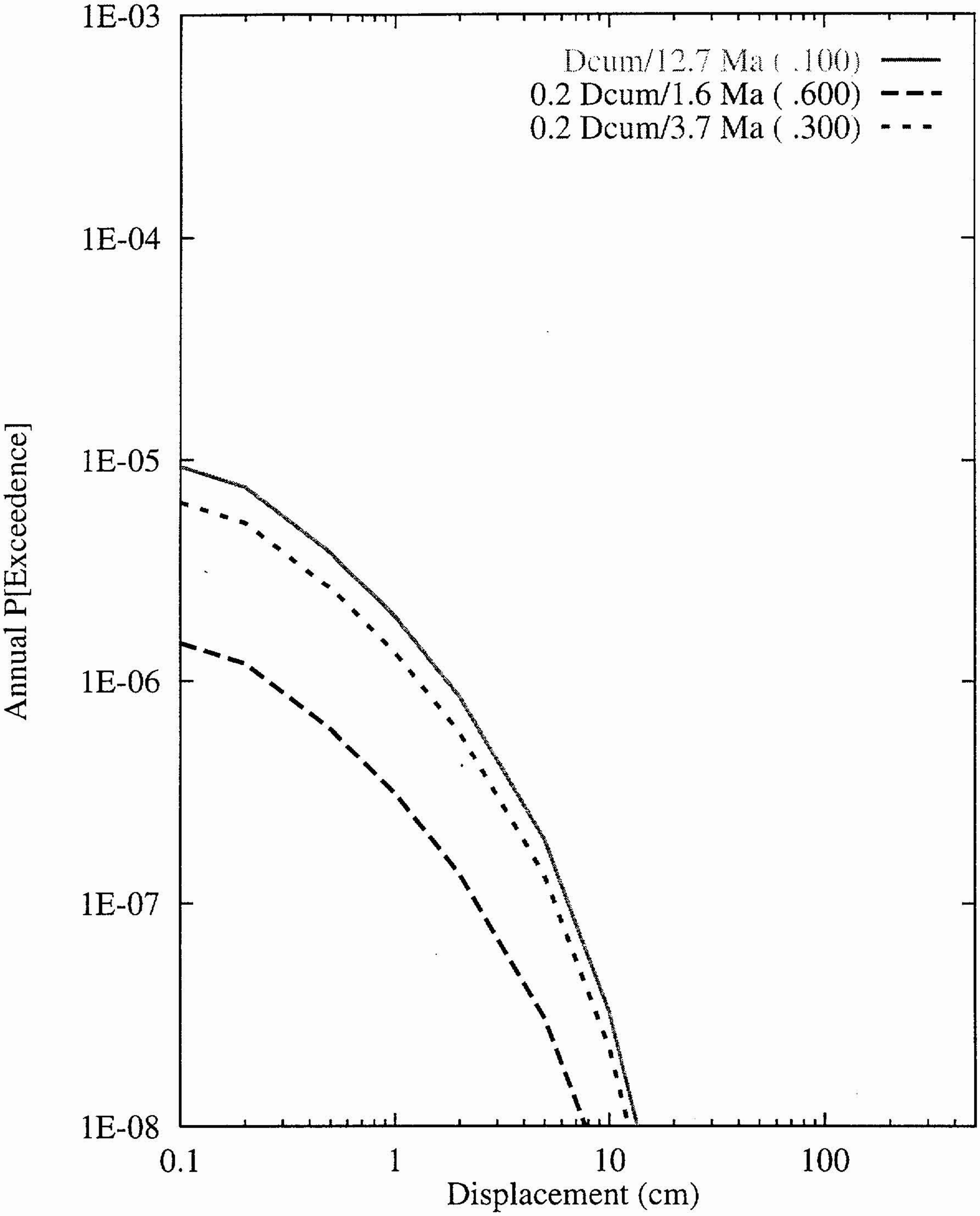

Figure 8-56 Sensitivity of displacement hazard for Site 7a to calculation of slip rate: RYA team, displacement approach

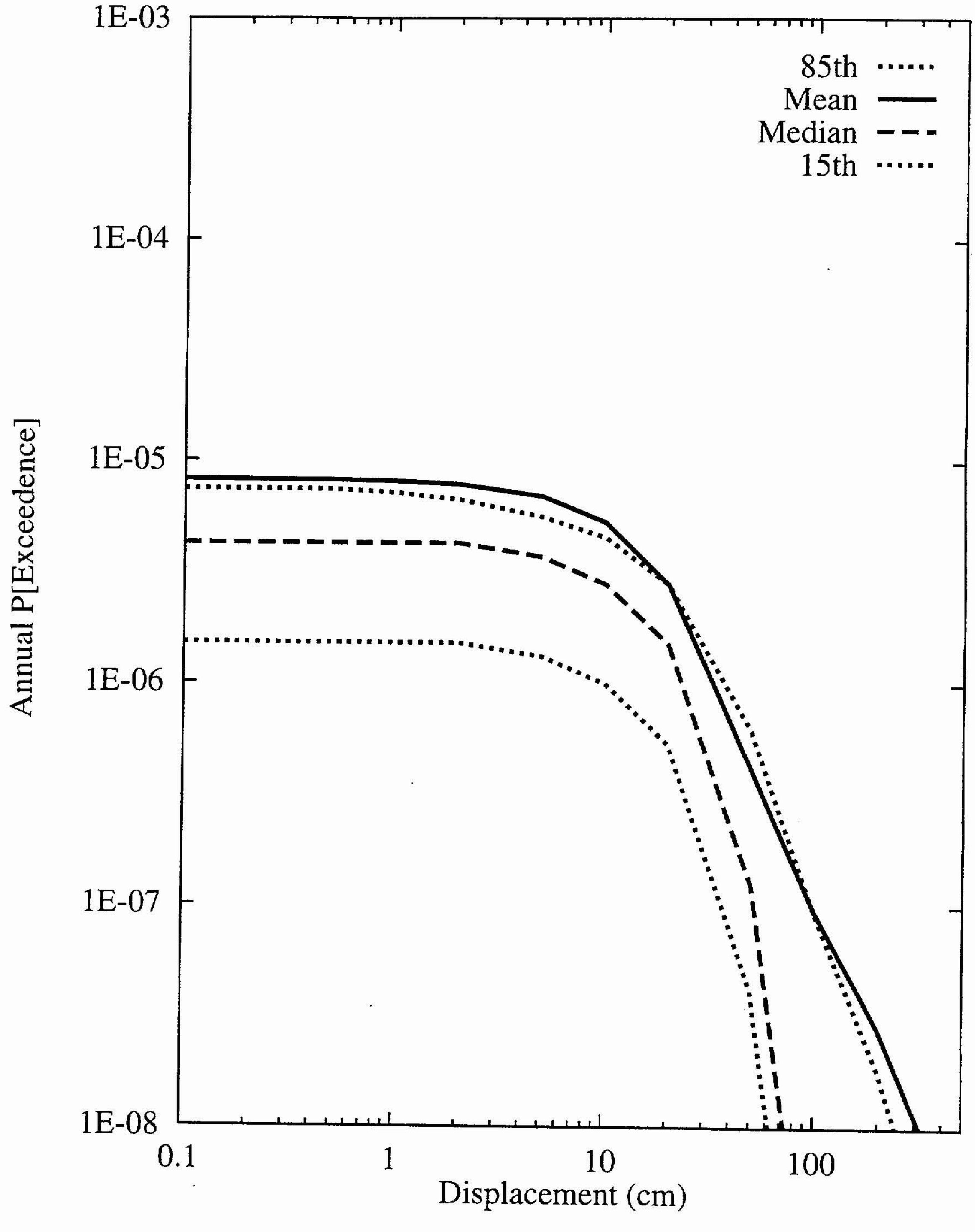

Figure 8-57 Summary hazard curves for Site 1: SBK team, earthquake approach

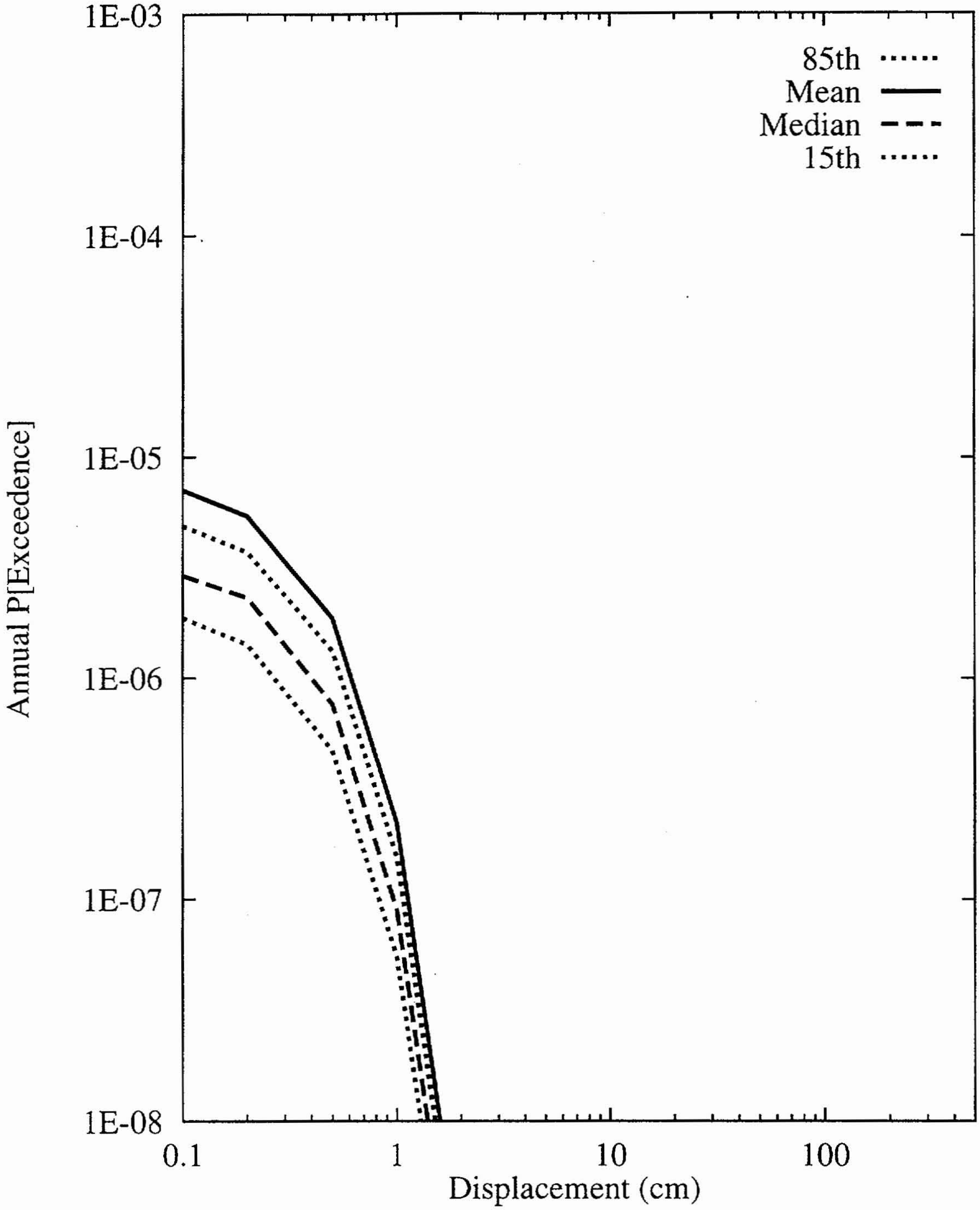

Figure 8-58 Summary hazard curves for Site 7a: SBK team, earthquake approach

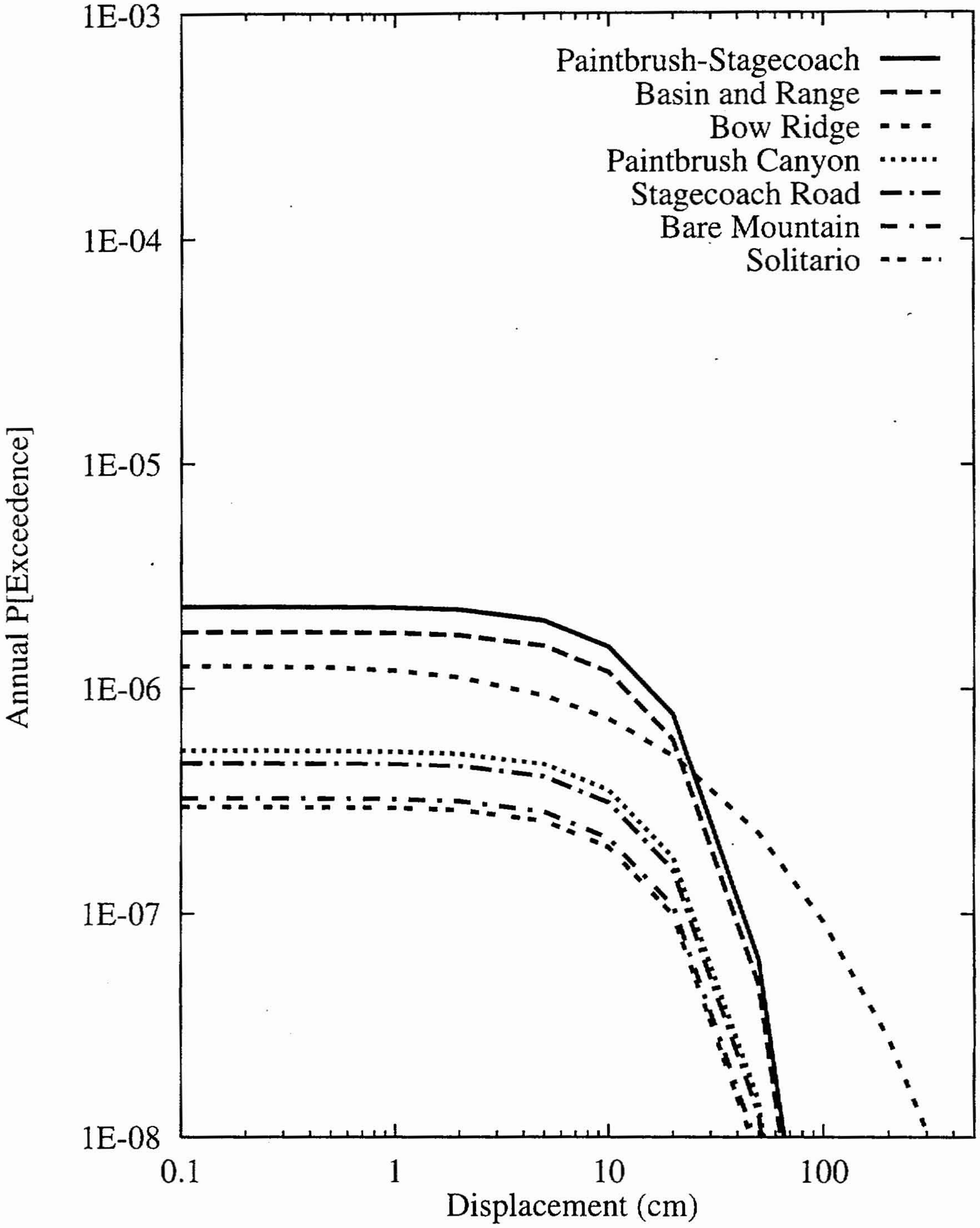

Figure 8-59 Mean hazard curves by source for Site 1: SBK team, earthquake approach

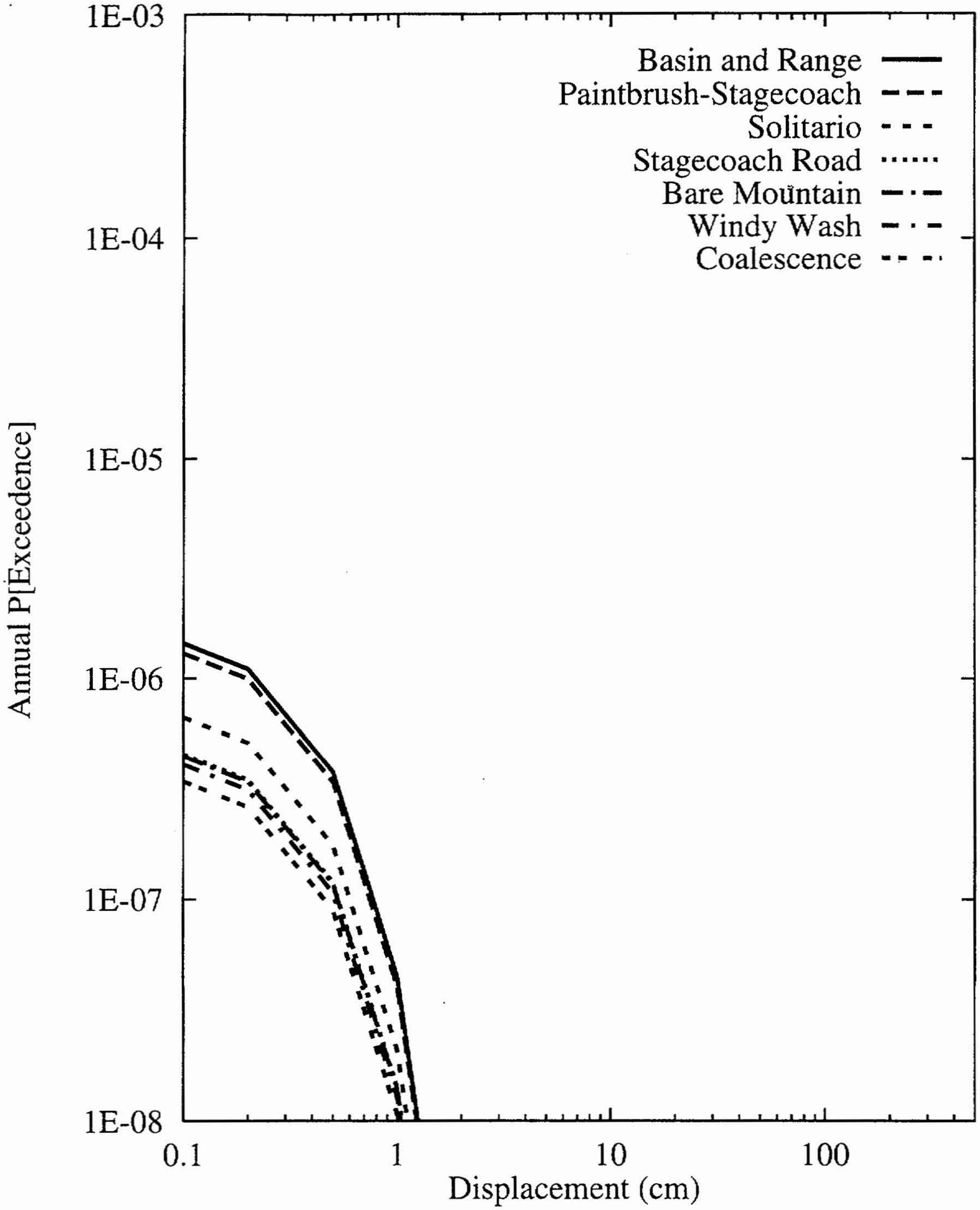

Figure 8-60 Mean hazard curves by source for Site 7a: SBK team, earthquake approach

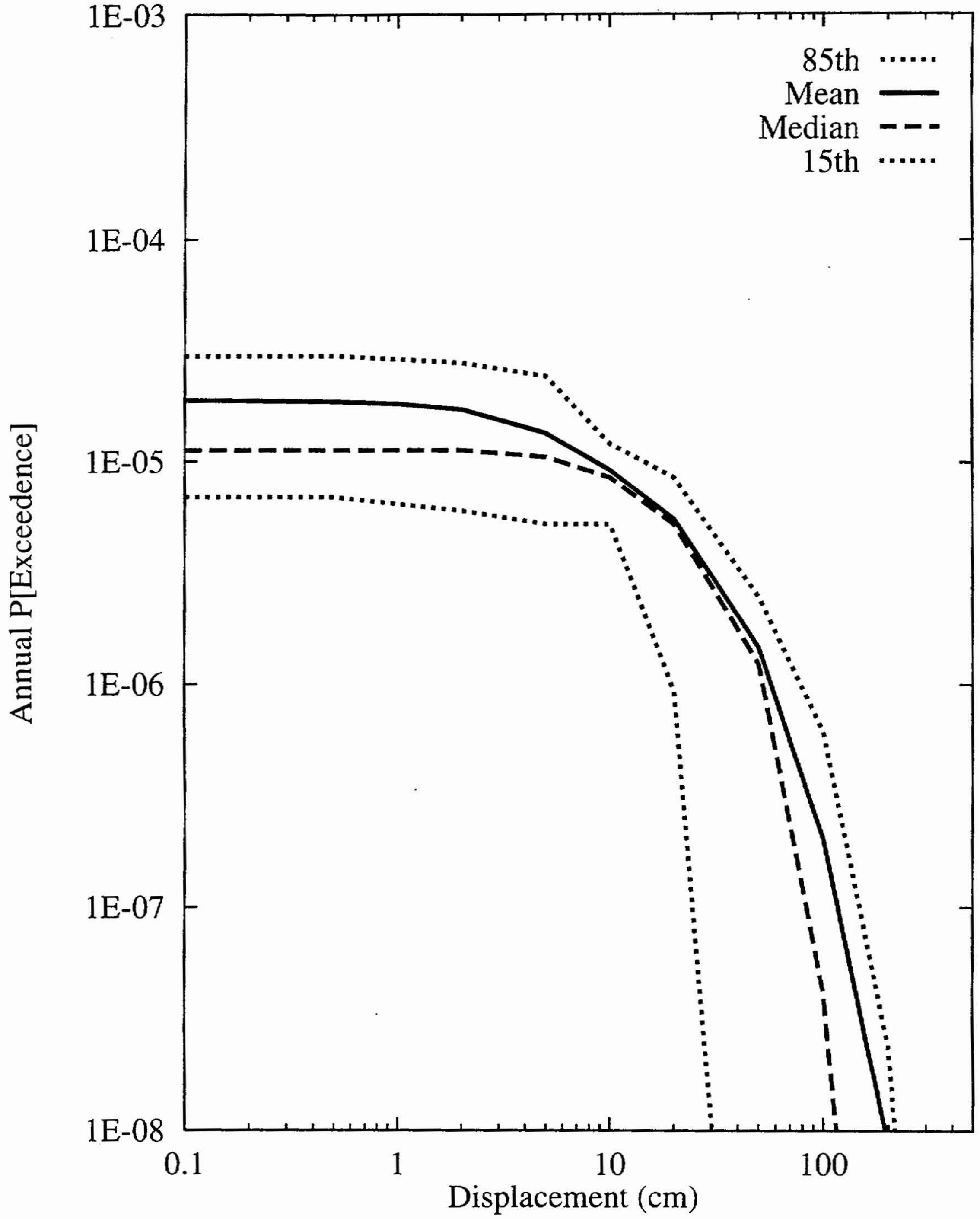

Figure 8-61 Summary hazard curves for Site 1: SBK team, displacement approach

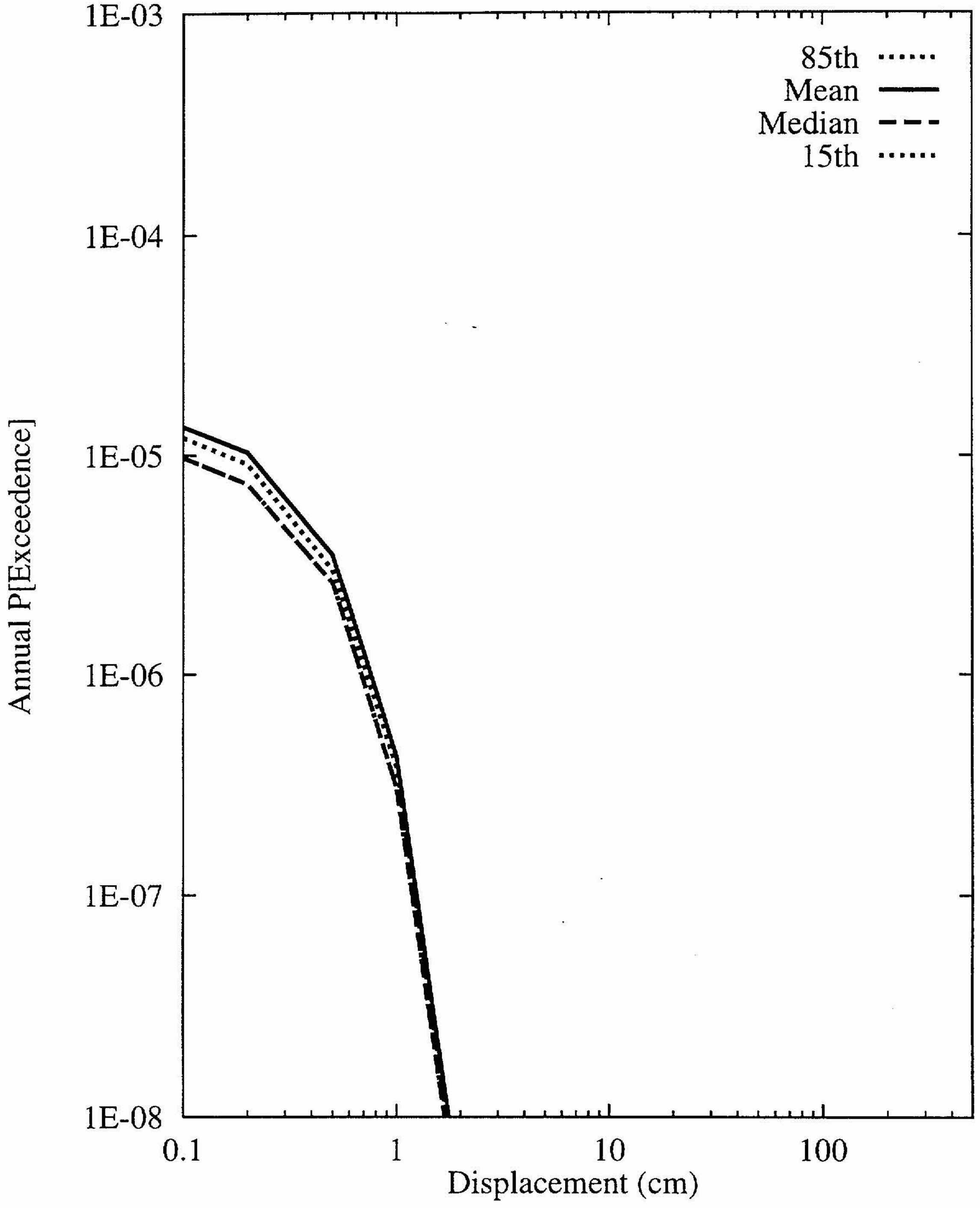

Figure 8-62 Summary hazard curves for Site 7a: SBK team, displacement approach

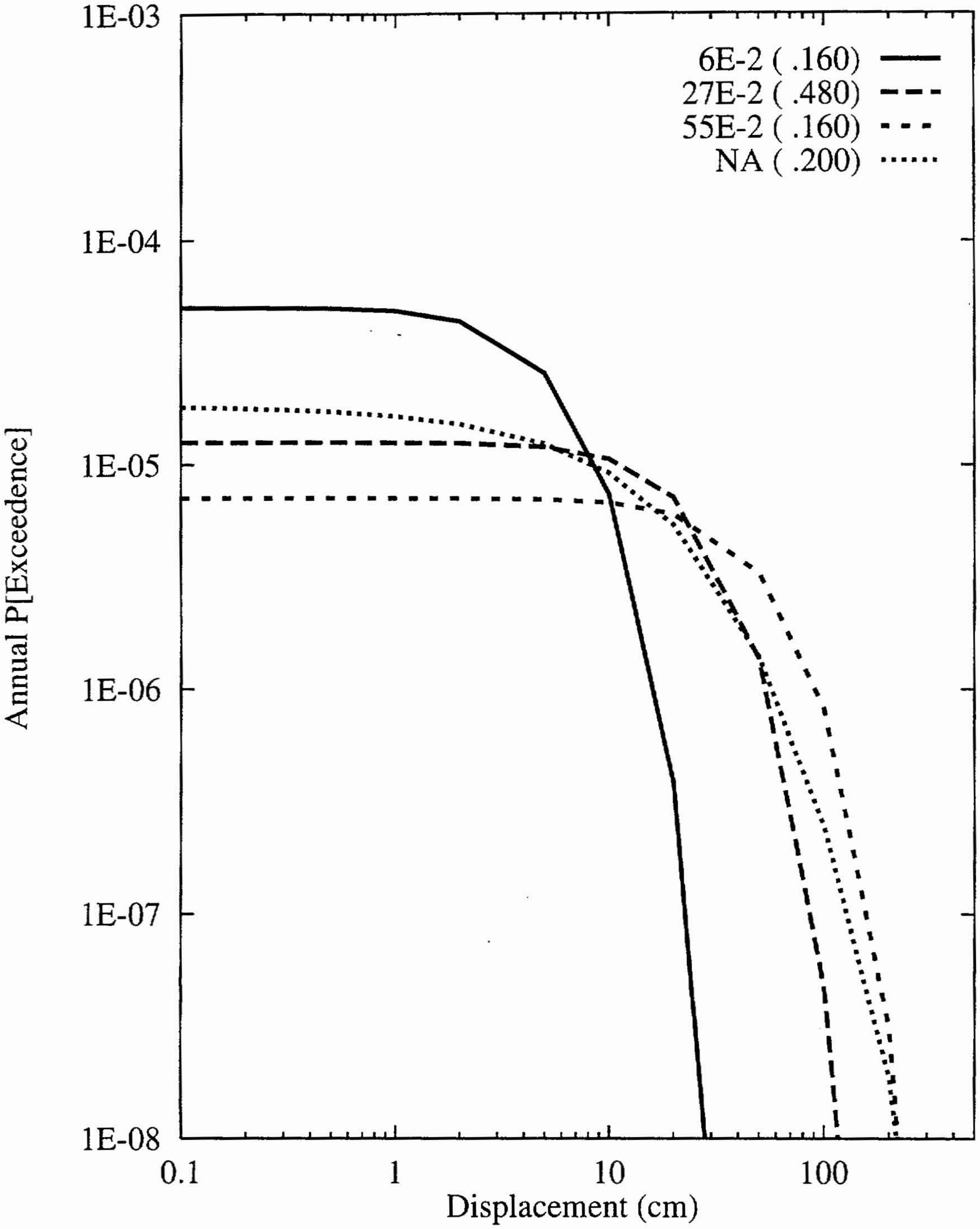

Figure 8-63 Sensitivity of displacement hazard for Site 1 to average displacement per event (m): SBK team, displacement approach

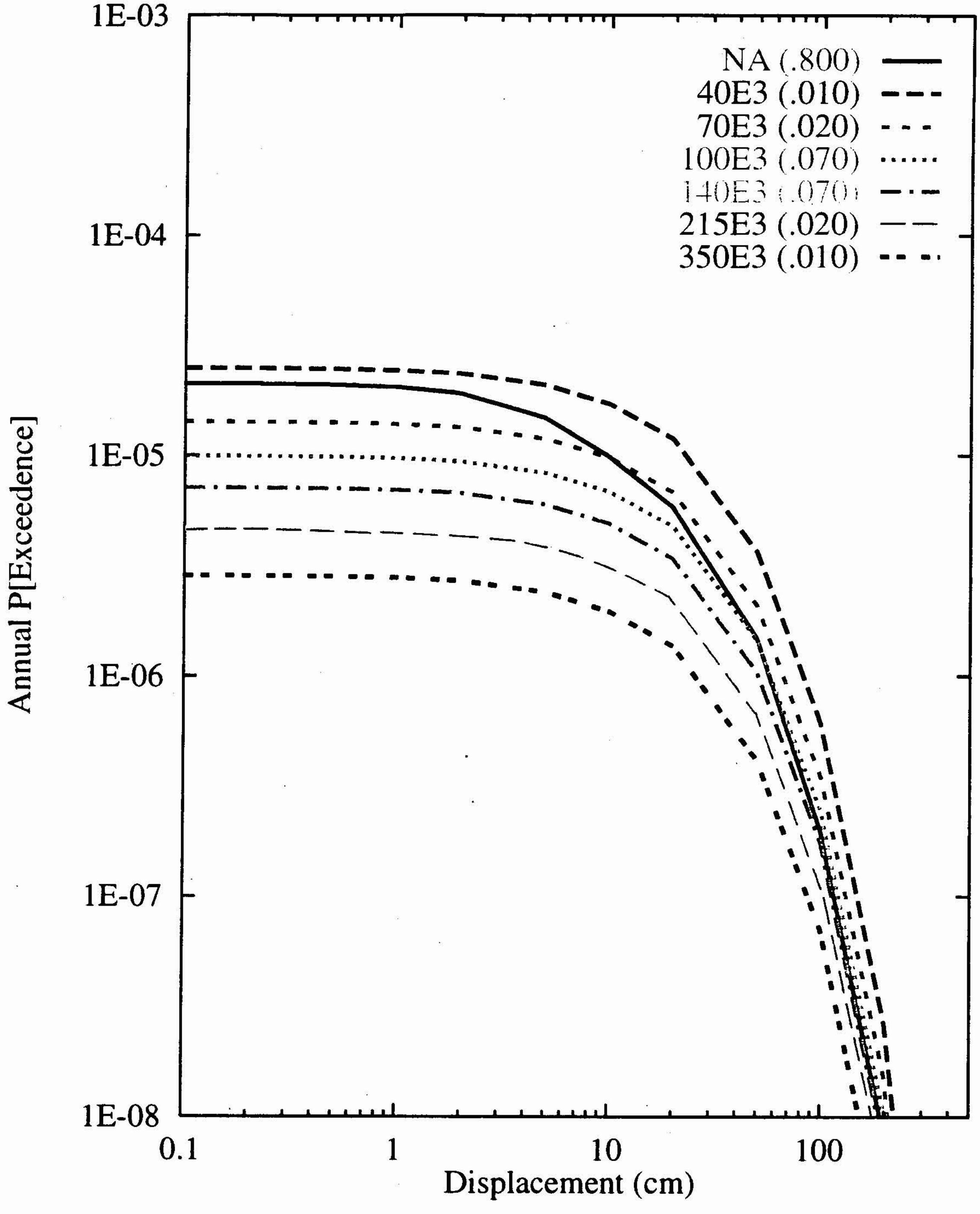

Figure 8-64 Sensitivity of displacement hazard for Site 1 to recurrence interval (yr): SBK team, displacement approach

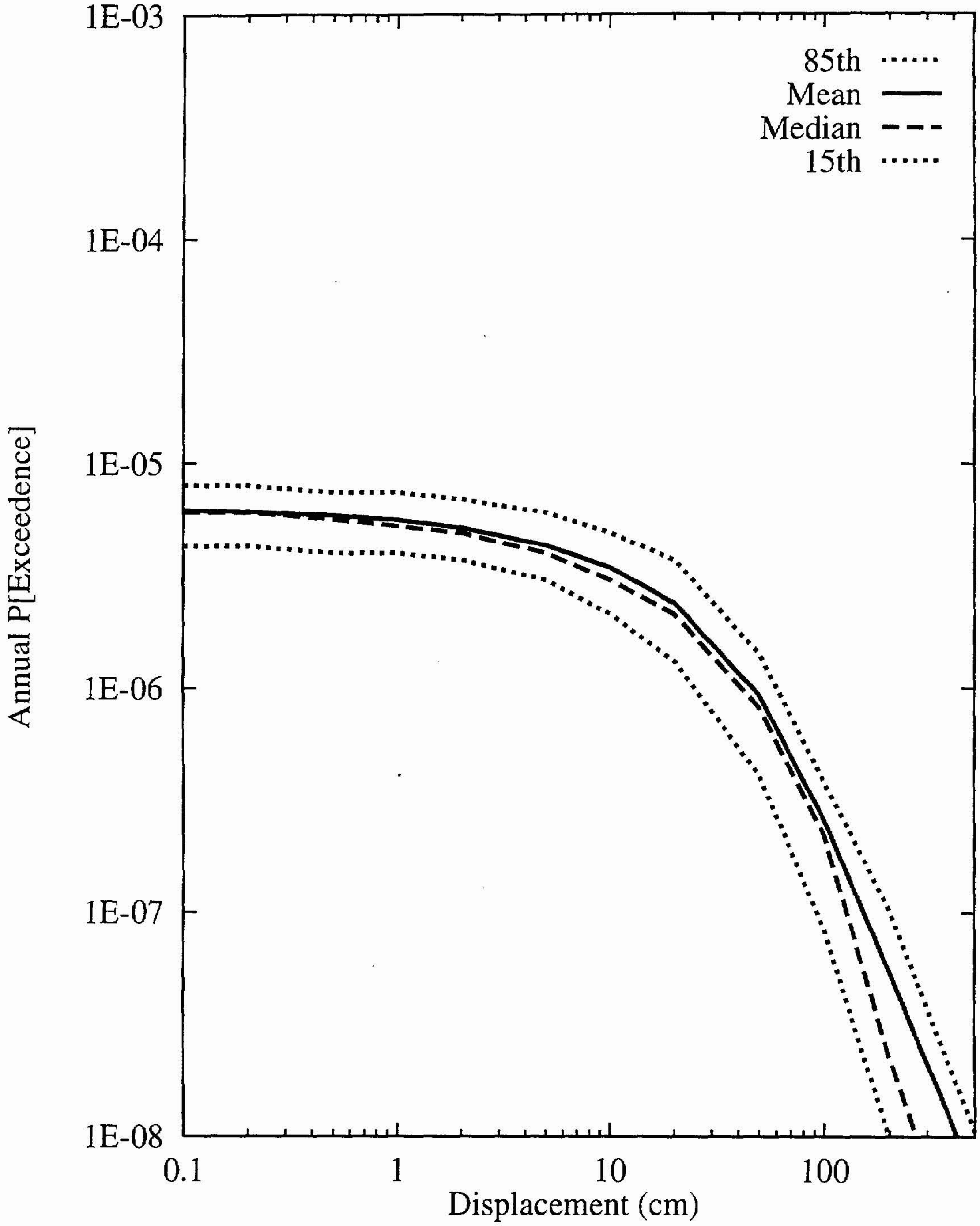

Figure 8-65 Summary hazard curves for Site 1: SDO team, earthquake approach

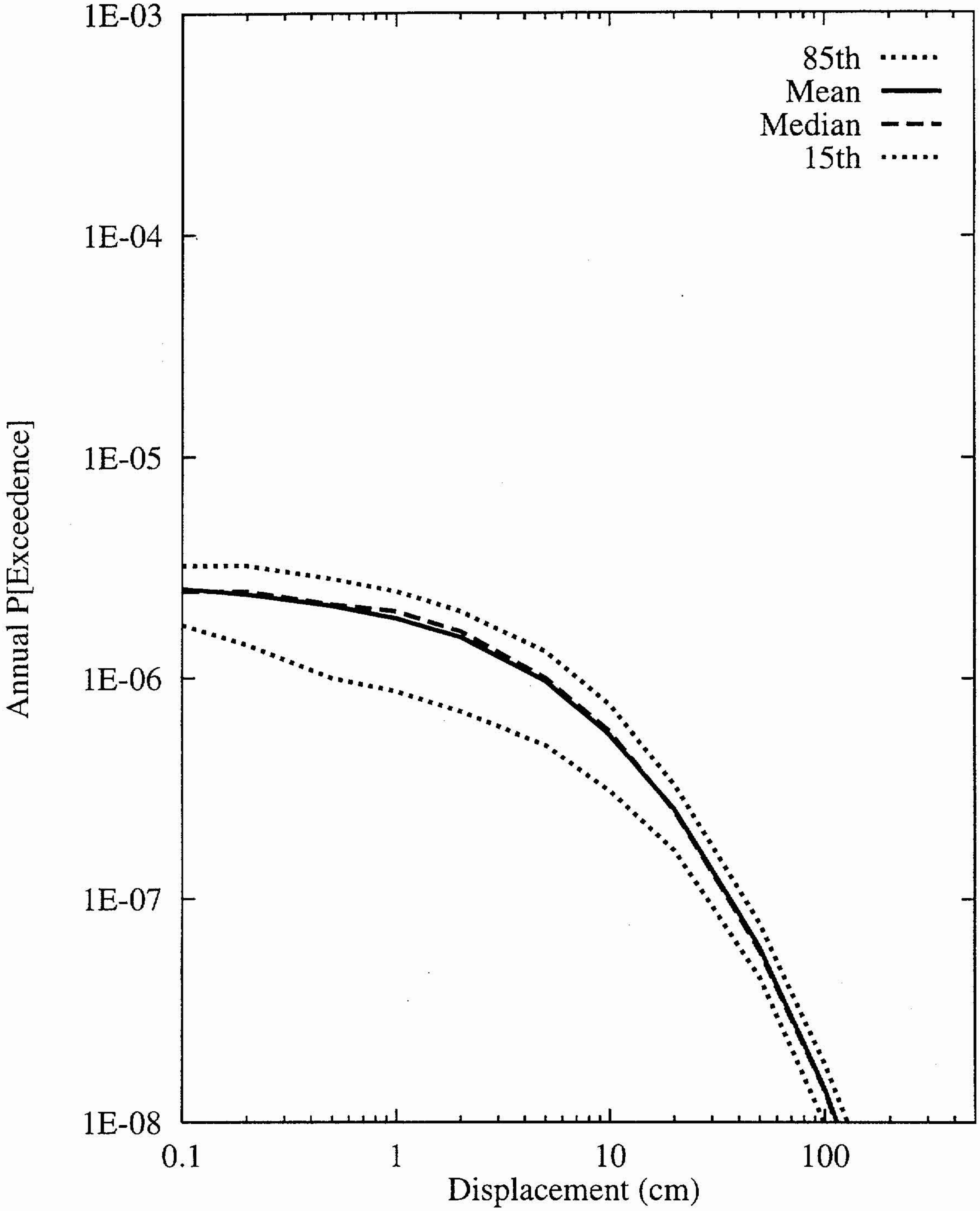

Figure 8-66 Summary hazard curves for Site 7a: SDO team, earthquake approach

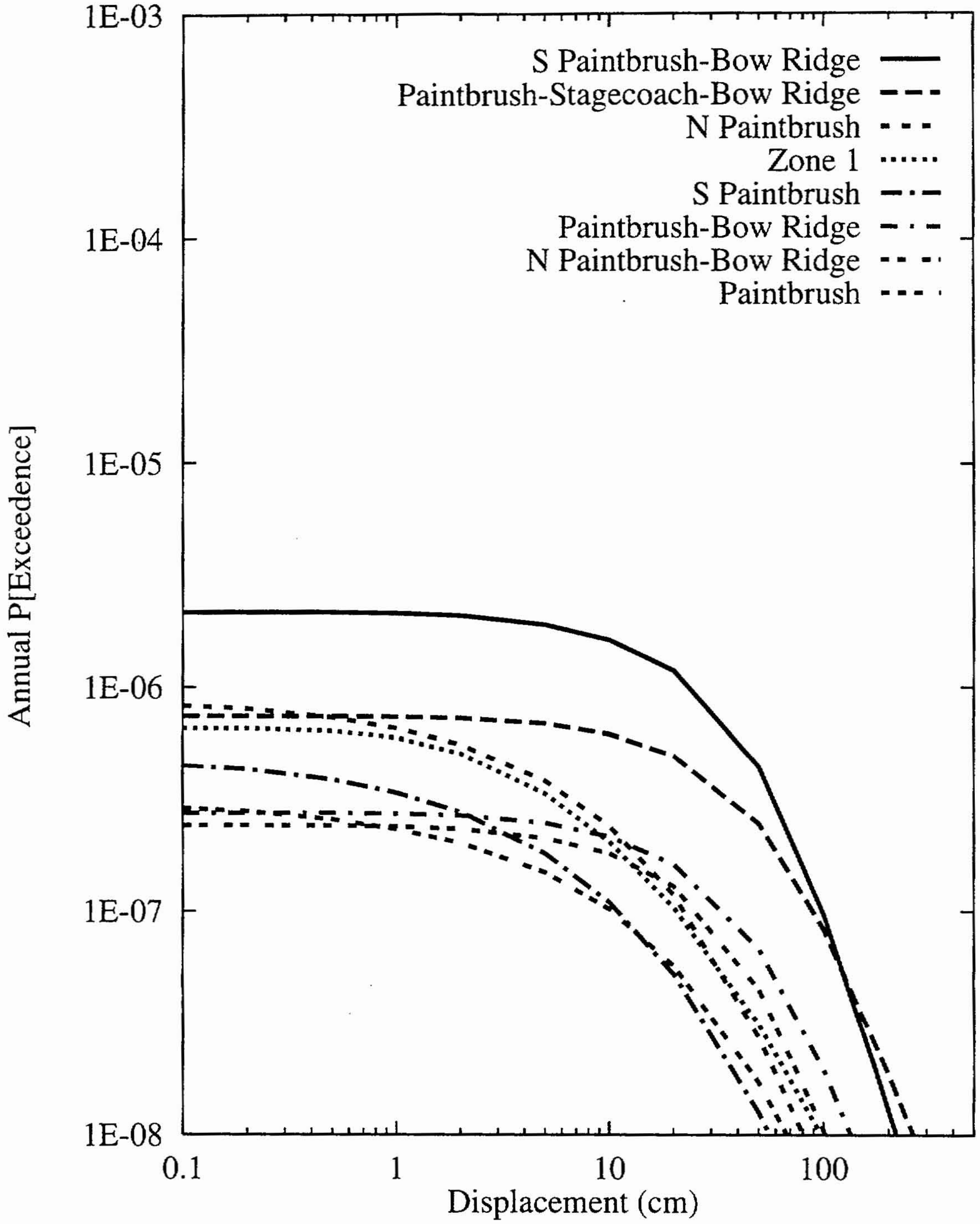

Figure 8-67 Mean hazard curves by source for Site 1: SDO team, earthquake approach

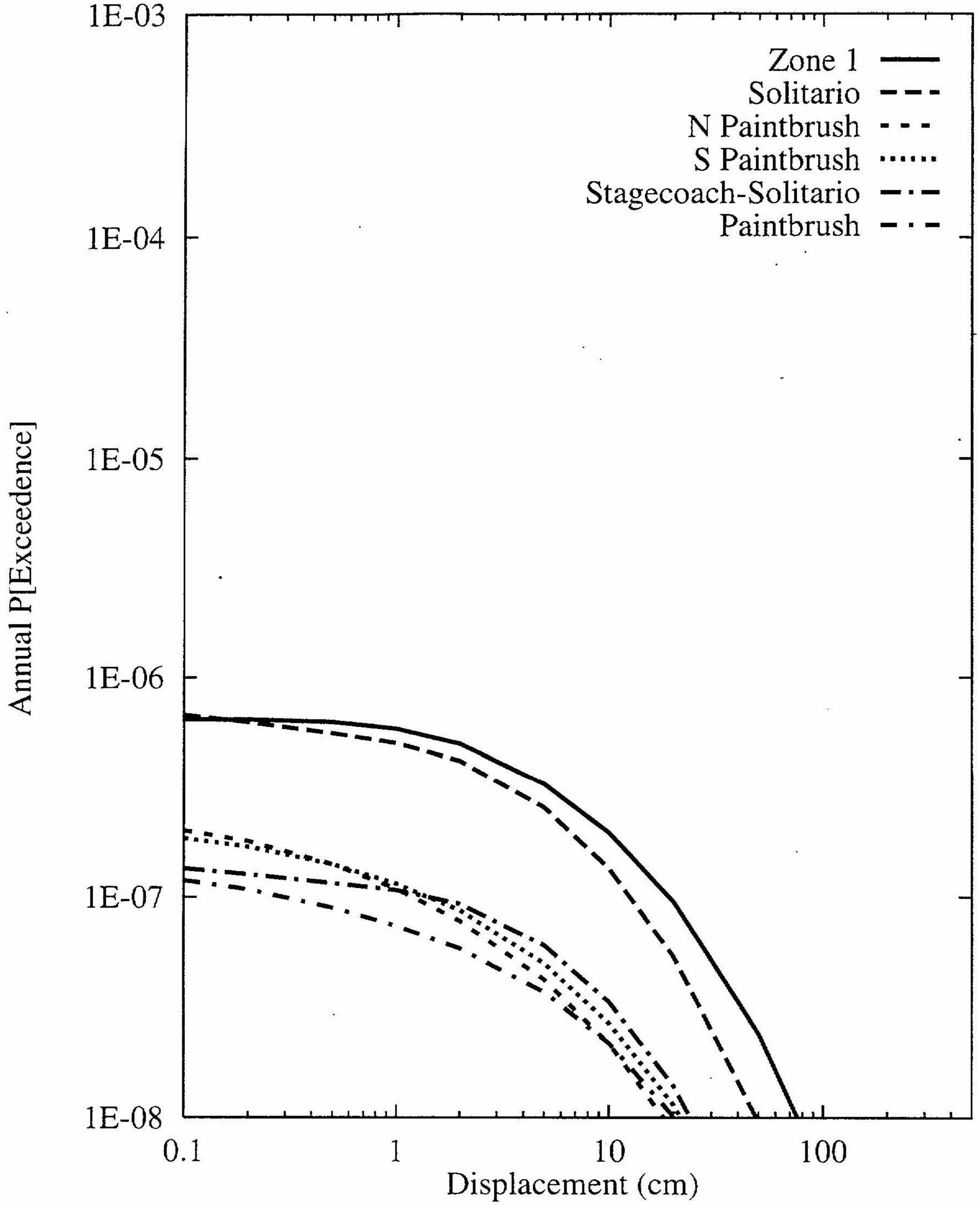

Figure 8-68 Mean hazard curves by source for Site 7a: SDO team, earthquake approach

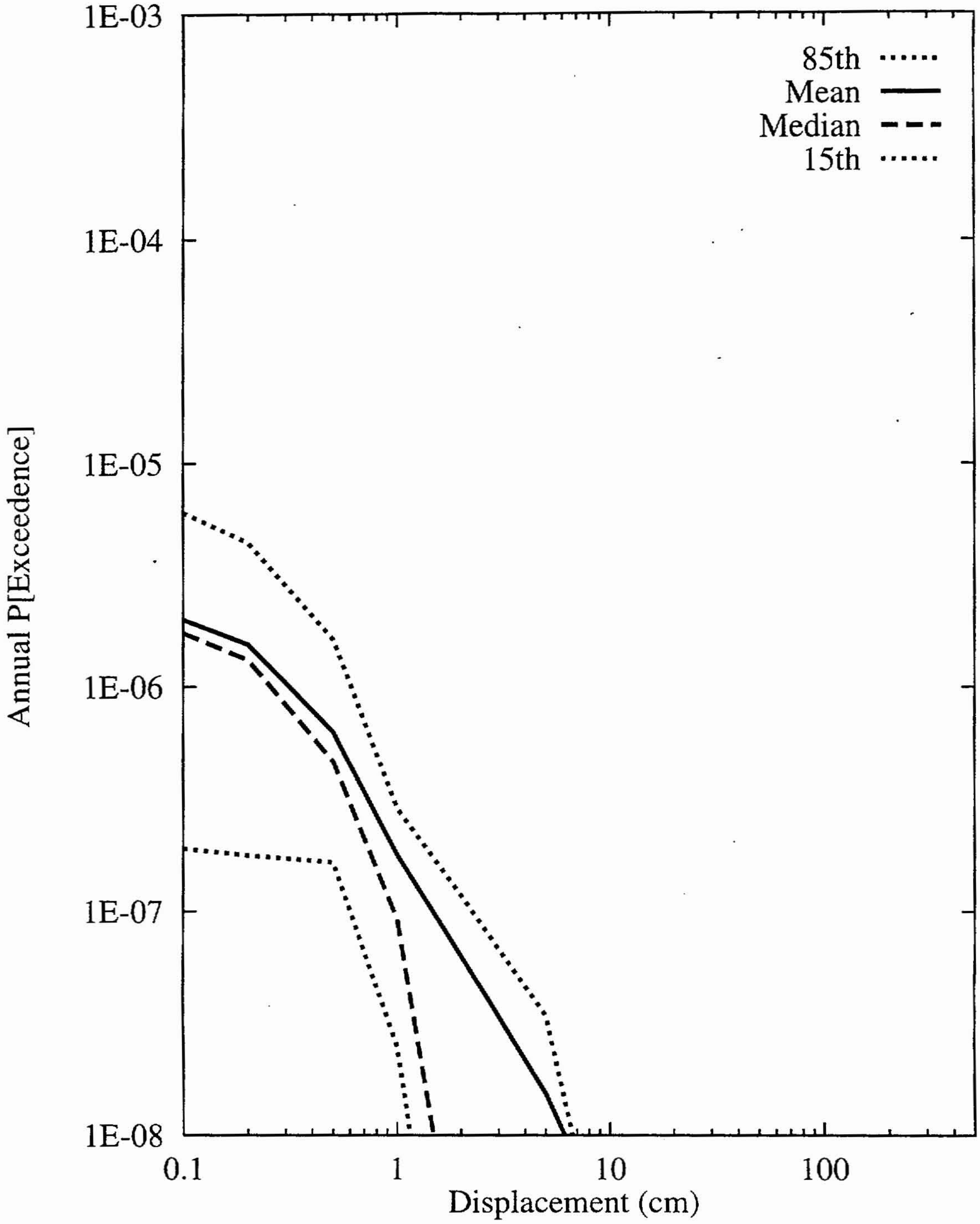

Figure 8-69 Summary hazard curves for Site 7a: SDO team, displacement approach

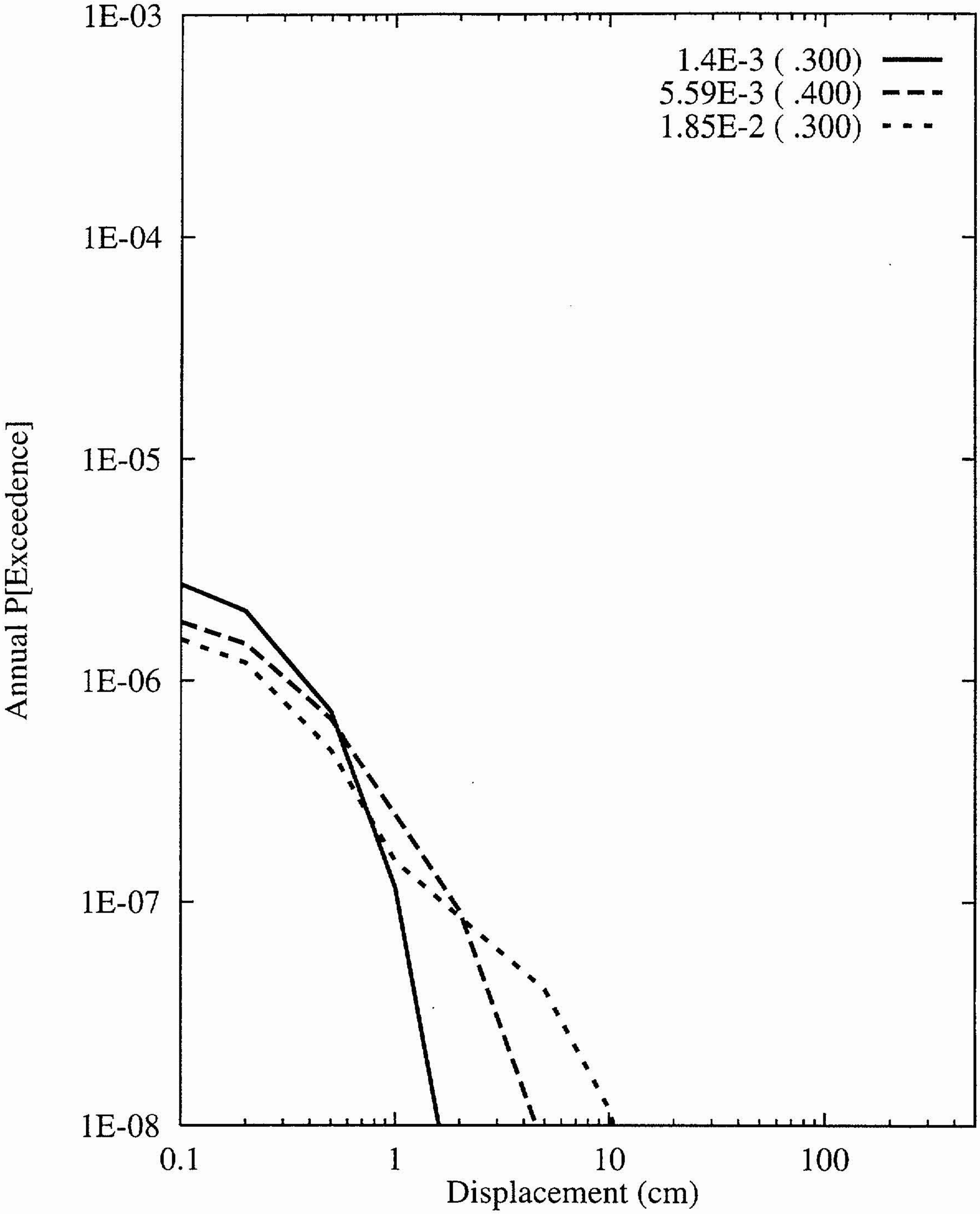

Figure 8-70 Sensitivity of displacement hazard for Site 7a to parameter beta: SDO team, displacement approach

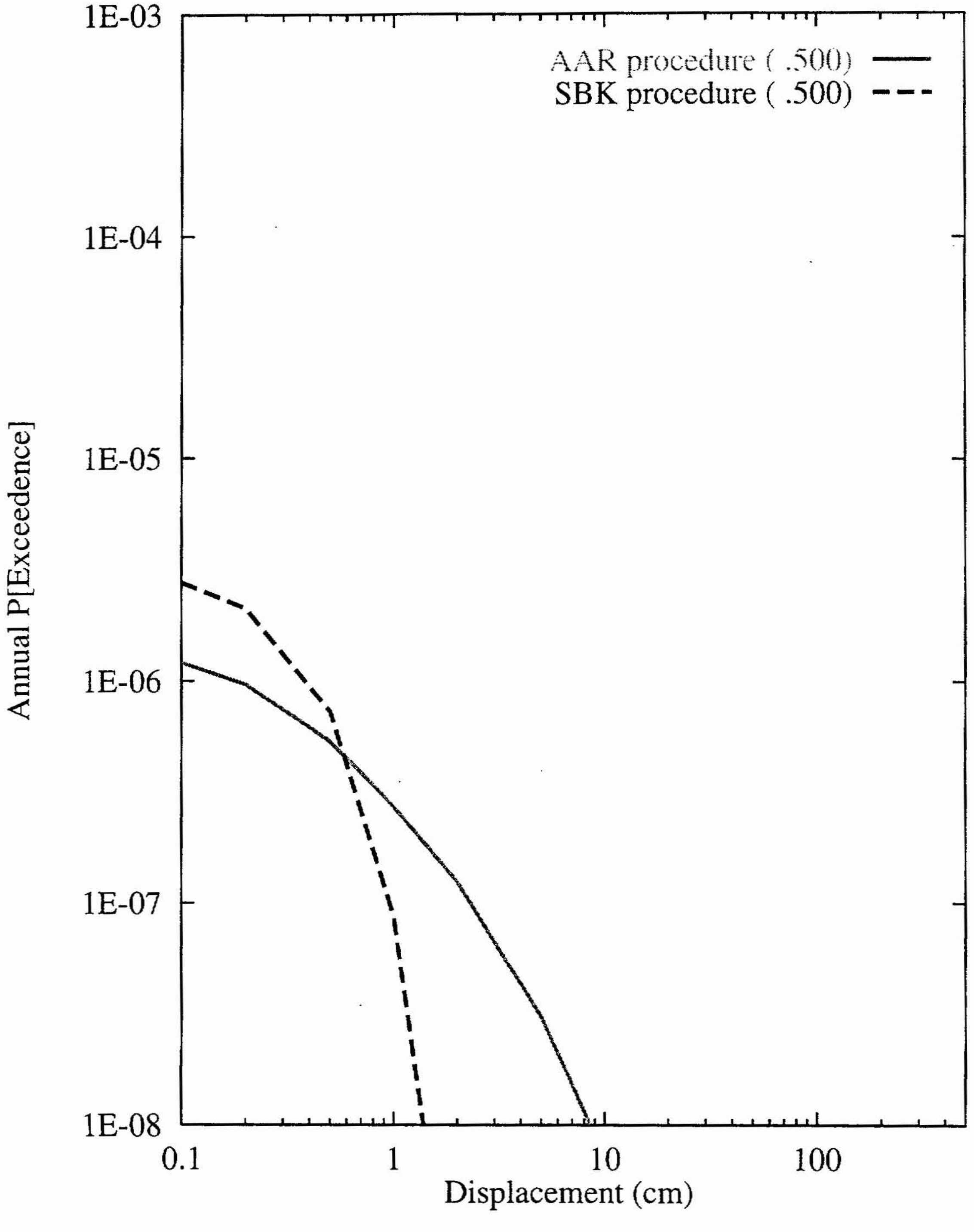

Figure 8-71 Sensitivity of displacement hazard for Site 7a to calculation of average displacement per event: SDO team, displacement approach

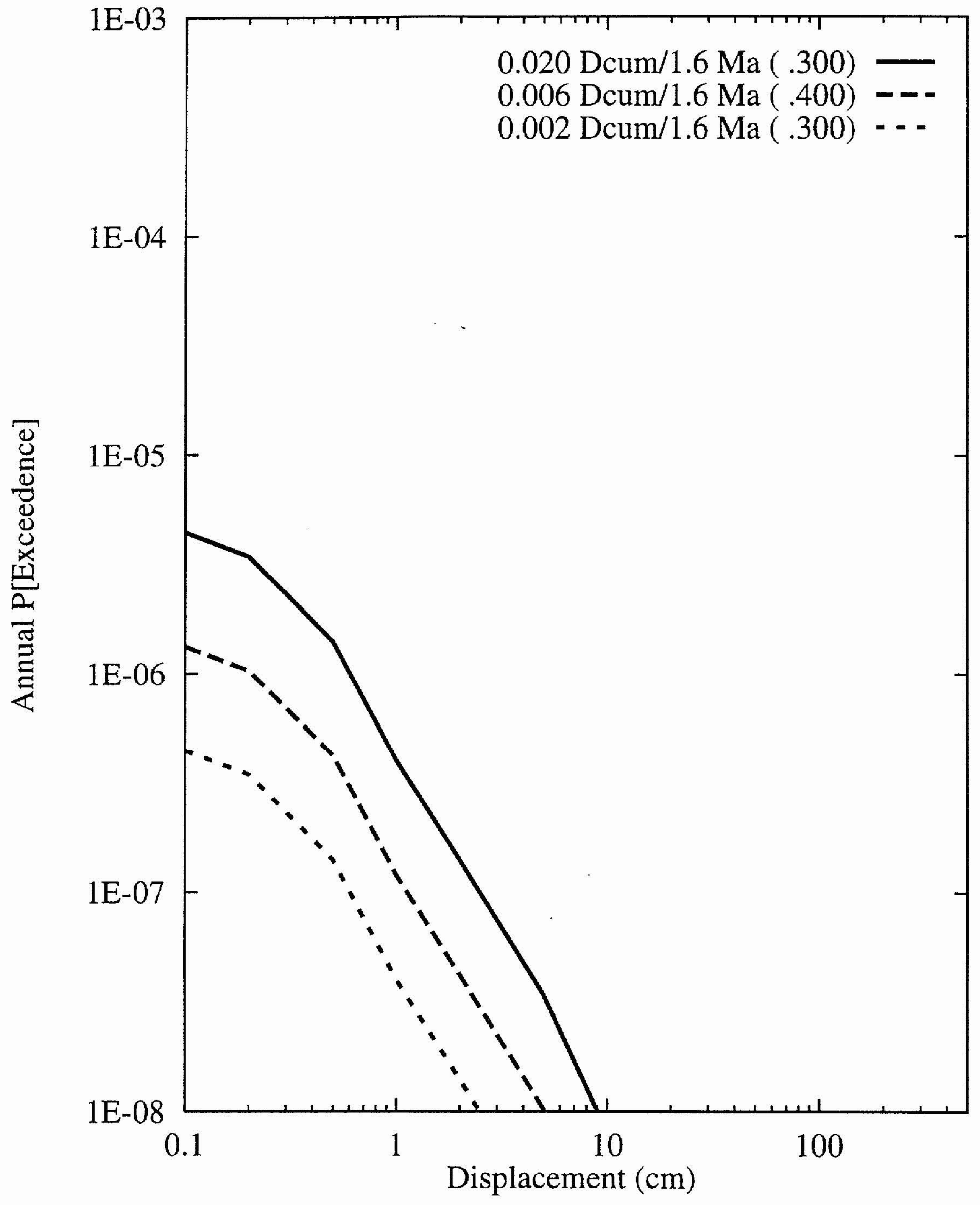

Figure 8-72 Sensitivity of displacement hazard for Site 7a to calculation of slip rate: SDO team, displacement approach

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PROBABILISTIC SEISMIC HAZARD ANALYSES FOR FAULT DISPLACEMENT AND VIBRATORY GROUND MOTION AT YUCCA MOUNTAIN, NEVADA

FINAL REPORT
VOLUME 2 APPENDICES

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Management & Operating Contractor

Ivan G. Wong and Carl Stepp
Report Coordinators

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APPENDIX A

BIOGRAPHIES OF EXPERTS

BIOGRAPHIES OF SEISMIC SOURCE AND FAULT DISPLACEMENT EXPERTS

Dr. Jon P. Ake is a seismologist whose recent research interests have been focused primarily on seismic hazard analyses, engineering seismology, and induced seismicity. He received his undergraduate degree in 1979 in geology and physics from Western State College. He then worked at the New Mexico Engineering Research Institute where he conducted research dealing with strong ground motions generated by explosions, the dynamic response of earth media, and the applications of signal analysis techniques to ground shock problems. From 1983 to 1987, Dr. Ake attended graduate school at the New Mexico Institute of Mining and Technology where he received a Ph.D. in geophysics in 1987. His research dealt with the analysis of microearthquake data applied to studies of crustal structure, seismic sources, and near-station effects. From 1987 to 1989 he had responsibility for operating a seismic network focused on assessing seismic hazard in the Colorado Front Range for Denver Water Department facilities. His research involved probabilistic seismic hazard analyses and application of inversion procedures. From 1989 to the present Dr. Ake has been employed by the U.S. Bureau of Reclamation (USBR) as a senior seismologist in the Seismotectonic and Geophysics Group. His duties include seismologic and tectonic fault assessments, estimation of strong ground motions by several techniques, and consultation on engineering geophysics. He has been responsible for review and coordination of seismic hazard and risk analyses and review of contract seismotectonic studies. Additional duties include operation, maintenance, and data analysis from two seismic monitoring networks in western Colorado. Current research involves application of finite source ground motion modeling to engineering analyses, risk-based seismic hazard assessment, and studies of induced seismicity.

Dr. R. Ernest Anderson received his Ph.D. from Washington University, St. Louis in 1962 after which he spent 11 years working on Atomic Energy Commission-sponsored geologic studies (mostly mapping at various scales) in and around the Nevada Test Site (NTS). This NTS background gives him a valuable perspective on a broad range of geologic problems in the Yucca Mountain area. Equally important, he has built on that background to become an expert on the structure and tectonics of the Basin and Range province by his mapping and topical studies in more than 40 mountain ranges throughout the province. For more than 20 years, his studies have dovetailed a broad range of regional and site-specific investigations bearing on seismicity and paleoseismicity including (1) mapping Quaternary fault scarps in western Utah and developing some of the first quantitative relations of the time dependence of scarp degradation, (2) coordinating U.S. Geological Survey (USGS) paleoseismic studies of the Wasatch fault in Utah, (3) developing an understanding of integrated focal mechanism and fault-slip data in central Utah, (4) evaluating hazards aspects of basaltic volcanism in southern Utah and adjacent Arizona, and (5) advising other agencies such as the USBR and U.S. Soil Conservation Service on seismic hazards aspects of dams in central and southwestern Utah. Dr. Anderson has a strong interest in paleohydrology and has authored papers on the paleohydrology of areas in Clark and Lincoln counties, Nevada, and a paper interpreting the impoundment-related seismicity at Lake Mead in terms of geographic contrasts in hydraulic continuity. His strongest current research interest is in improving understanding of the 3-D aspects of the deformation field in the Basin and Range province and the role of plutonism in shaping that deformation field – two subjects of potentially great importance to understanding the seismotectonics of Yucca Mountain.

Mr. Larry W. Anderson is a geologist with over 17 years of experience in the identification, evaluation, and seismic hazard analysis of active and potentially active faults as applied to engineered facilities. Born in San Francisco, California, Mr. Anderson attended Brigham Young University and the University of Colorado. He received an M.S. degree from the University of Colorado in 1976. From 1977 to 1980, Mr. Anderson was employed by Fugro, Inc., where he worked on geotechnical investigations for major facilities including fault-related studies for several existing or planned nuclear power plants in the western U.S. While at Fugro, he compiled the first Quaternary fault map of the state of Utah. In 1981, Mr. Anderson began work with USBR's Seismotectonic Group. Since that date, Mr. Anderson has personally conducted or been responsible for numerous seismic hazard studies for USBR dams and facilities throughout the western U.S. Many of these studies included detailed fault evaluations such as those for the Ortigalita fault in California, the Pyramid Lake fault zone in Nevada, and the Horseshoe fault in Arizona. Results of these studies have been published in several publications. Since 1992, Mr. Anderson has been the Principal Investigator on the study of "Quaternary Faulting within 100 km of Yucca Mountain, Including the Walker Lane" for the Yucca Mountain Project. The major emphasis for this study has been on evaluating the Quaternary paleoseismic history of the Death Valley-Furnace Creek fault zone and the Bare Mountain fault.

Dr. Walter J. Arabasz graduated summa cum laude from Boston College in 1964 with a B.S. in Geology. He obtained an M.S. and Ph.D. in geology at the California Institute of Technology in 1966 and 1971, respectively (with a minor in geophysics). He was also a Post-Doctoral Research Fellow at the Department of Scientific and Industrial Research in New Zealand (1970-73). He has more than 27 years of experience in conducting research in seismology and tectonics, with current interests focusing on network seismology, earthquake hazard analysis, tectonics and seismicity of the intermountain area, and statistical patterns of earthquake occurrence. He has been the director of the University of Utah Seismograph Stations since 1985 and research professor at the University of Utah since 1983. He is Chair of the Utah Seismic Safety Commission and recently served as Chair of the Council of the National Seismic System (1995-97), as a member of the Board of Directors of the Seismological Society of America (1994-97), and as a member of the National Research Council's Panel on Seismic Hazard Evaluation (1992-96). His experience with regard to Yucca Mountain is extensive, including (1) member of the Peer Review Group for Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain (1991), (2) member of the Specialist Panel for the Earthquakes and Tectonics Expert Judgment Elicitation Project (1991-92), and (3) technical reviewer for reports on seismic hazards methodology for Yucca Mountain and on seismic design inputs for the Exploratory Studies Facility (1993-94). He was also a member of the Seismic Hazard Methodology Team for the Electric Power Research Institute's (EPRI) Seismic Hazards Research Program (1984-87).

Dr. Ronald Bruhn received his B.A. in geology from Alaska Methodist University in 1971. He received his Ph.D. in geology from Columbia University in 1976. He is a Professor of Geology in the Department of Geology and Geophysics at the University of Utah, where he has worked since 1976. He teaches courses in physical geology, structural geology, engineering geology, and tectonics. Dr. Bruhn's expertise includes structural geology and tectonics, and the application of structural geology to problems in mining and petroleum geology, and seismic hazards. In earthquake hazards studies, he specializes in the applications of structural geology to infer rupture characteristics, including segmentation of fault zones, fluid flow in fault zones, and earthquake mechanics. He has conducted seismic hazards projects in strike-slip, normal, and reverse faulting regimes in the western U.S., Alaska, Israel, South America, and South Korea. He has extensive experience with both regional and detailed studies of faulting in the Basin and Range province, including the tectonic evolution of the Mesozoic and Cenozoic Cordillera. He has also completed studies on the seismogenic properties of faults in the Central Nevada Seismic Belt. Currently he is developing new methods to date paleo-earthquakes using cosmogenic isotopes. His research and consulting work is supported by the National Earthquake Hazards Reduction Program, the National Science Foundation (NSF), the Norwegian Petroleum Directorate, the U.S. Department of Energy (DOE), and private firms.

Mr. Craig dePolo received his B.S. degree in geology from California State University, Sacramento and his M.S. degree in geology from University of Nevada, Reno. He is presently a Research Geologist for the Nevada Bureau of Mines and Geology and has been involved with seismic hazard characterization and research for the past 18 years, 12 of which have been studying the Basin and Range province. He has been involved with the seismic hazard characterization of Yucca Mountain, Nevada for the last 9 years. Mr. dePolo has conducted aerial reconnaissance and photographic missions of active faults and historical earthquake ruptures, worked on logging and interpreting trenches, and has, to date, characterized the seismic hazard of several hundred faults. He has worked on fault segmentation theory using historical earthquakes as a data base and a fault slip-rate theory using fault data from Nevada and California. He has mapped out the surface ruptures from the 1932 Cedar Mountain earthquake, and worked on trench studies along these breaks. Recent research has included an analysis of the maximum background earthquake for the Basin and Range province and studies of multiple segment and distributed surface ruptures. He is currently involved in devising and managing an earthquake scenario project in the Reno-Carson City urban corridor. Mr. dePolo is an active participant in the Nevada Earthquake Safety Council, and is the past Chairman and currently serves on the Executive Committee of the Western States Seismic Policy Council.

Dr. Diane Irene Doser obtained her B.S. in applied geophysics from Michigan Technical University. She obtained her M.S. and Ph.D. in geophysics from the University of Utah. She was a Post-Doctoral Fellow at the California Institute of Technology. She has been at the University of Texas at El Paso since 1986 where she now is a professor and the director of the Kidd Memorial Seismic Observatory. Her experience related to seismic sources in the western U.S. is extensive. Both her M.S. and Ph.D. work related to earthquakes of the intermountain west. She has published 16 papers related to source processes of U.S.

intermountain earthquakes, including 4 papers on Nevada earthquakes. She has also published papers on the source processes of earthquakes in other continental rifts (Baikal, east Africa), on southern California-northern Baja California earthquakes, and on papers related to induced seismicity in west Texas oil fields. Additionally, since 1987, Dr. Doser has been Co-Principal Investigator on numerous grants from the Texas Low-Level Radioactive Waste Authority to assess seismic hazards associated with two proposed disposal sites in west Texas, and to operate seismic monitoring networks in these regions.

Dr. Christopher J. Fridrich obtained both his doctorate and masters degrees in geology from Stanford University where he conducted research on the petrology and structure of the Grizzly Peak caldera in Colorado. He also has a bachelor's degree in geological engineering from Michigan Technical University. Dr. Fridrich has extensive mapping experience throughout the western U.S., particularly investigating volcanic deposits. He has been working on the Yucca Mountain project since 1988, including both research, oversight, and coordination duties. He is responsible for geologic mapping of the Crater Flat basin and structural analysis of the map data for the purpose of developing constraints on tectonic models to be used in seismic hazard assessments of the Yucca Mountain site. He is also principal investigator for studies of tectonic effects on the hydrology of Yucca Mountain, which includes hydrogeologic studies, surface and subsurface mapping, and evaluation of several types of geological, geophysical, and hydrologic data. Prior to working on the Yucca Mountain project, Dr. Fridrich was a Research Fellow for the American Museum of Natural History and has several years of experience working in the mineral and oil industries.

Dr. Peter L.K. Knuepfer has worked on paleoseismic and geomorphic studies of active faults in the Basin and Range of the western U.S. throughout his professional career. He received his B.S. in 1976 and his M.A. in 1977 from Stanford University, after which he spent 4 years with Woodward-Clyde Consultants. He was a member of the Woodward-Clyde Consultants team that pioneered trenching of normal faults for paleoseismic analysis along the Wasatch fault in the late 1970s. As a graduate student at the University of Arizona in the early 1980s, he assisted in trenching studies of a low-slip-rate fault, the Santa Rita Piedmont fault, south of Tucson, Arizona, and he worked with Prof. William B. Bull and other students on studies of the 1887 surface rupture and previous breaks along the Pitaycachi fault in northern Sonora, Mexico. He completed his Ph.D. there in 1984. Since joining the faculty of Binghamton

University in 1986, Dr. Knuepfer has studied the paleoseismicity of the Lemhi fault in Idaho with a group of students (jointly with Woodward-Clyde Federal Services and personnel at the Idaho National Engineering Laboratory) and more recently has been a team member and/or reviewer of trenching studies along the southern Lemhi and Lost River faults. This work led to Dr. Knuepfer's inclusion in an expert panel solicitation regarding earthquake hazards at the Idaho National Engineering Labotatory (INEL), under the direction of Lawrence Livermore National Laboratory. Further work in Idaho, in early stages of research, focuses on the temporal relationship and possible strain partitioning between basaltic volcanic eruptions in the Eastern Snake River Plain and faulting on the Lemhi and Lost River faults. Dr. Knuepfer has other extensive experience in active tectonics and paleoseismic studies in California and overseas in Taiwan and New Zealand. Recent research in New Zealand and Taiwan has focused on studies of terraces formed by river incision to deduce rates and styles of uplift during active mountain-building.

Dr. James P. McCalpin is President of GEO-HAZ Consulting, Inc., and is also Research Associate Professor of Geology at Utah State University and Special Graduate Faculty at the University of Colorado, Boulder. He has been performing neotectonic studies since 1976. Dr. McCalpin has developed an international reputation for trenching faults and using numerical dating techniques to reconstruct the magnitude and timing of paleoseismic events. He recently edited the first reference book in paleoseismology ("Paleoseismology," Academic Press, 1996) along with 10 coauthors from government and academia. Between 1982 and 1992, Dr. McCalpin was the Principal Investigator on 10 research grants, funded by the USGS and NSF, to decipher the Quaternary history of faulting on various large normal faults in the western U.S. During these studies, he developed (along with Dr. S.L. Forman) a technique for combined radiocarbon and thermoluminescence dating of fault zone sediments that provides the best dating control yet achieved for many tectonic and climatic settings. His synthesis of the Holocene paleoearthquake history of the Wasatch fault zone, Utah, is the basis for the most up-to-date estimates of future earthquake probability (work with USGS collaborator S.P. Nishenko).. More recently he has been an expert reviewer for seismic hazards assessments of two DOE facilities, the Rocky Flats Plant, Colorado, and Los Alamos National Laboratory, New Mexico. His current research involves statistical analysis of paleoseismic data for application to logic trees and probabilistic seismic hazard analyses, particularly with reference to normal faults and the western USA.

Dr. Dennis W. O'Leary has been a research geologist with the USGS since 1972 when he received a Ph.D. in geology from Penn State University. Dr. O'Leary has taken on a wide variety of research tasks in various geologic settings. He has performed bedrock and surficial geologic quadrangle mapping at scale of 1:24,000 in Massachusetts and Connecticut, and conducted remote sensing investigations in the Tonopah, Nevada area, eastern Missouri, the Mississippi embayment, the Paradox Basin in Utah, and eastern Maine, in order to analyze fault and fracture patterns relevant to seismicity, ore mineralization, and bedrock integrity for nuclear waste storage site evaluation. Dr. O'Leary also conducted marine seismic and sidescan sonar surveys (GLORIA) along the U.S. Atlantic coast in order to assess seafloor stability and geological processes within the U.S. Exclusive Economic Zone. Since 1992, Dr. O'Leary has conducted tectonics evaluation studies for the USGS Yucca Mountain Project Branch. Principal tasks include evaluation and formulation of tectonic models for Yucca Mountain and its geologic setting, and characterization of northeast-striking strike-slip faults (chiefly the Rock Valley fault zone). Dr. O'Leary has also consulted on a variety of other tectonic-related problems, including seismic hazards analysis, performance assessment, and history of Neogene and Quaternary faulting in the Yucca Mountain area. His current research specializes in tectonic processes and tectonic effects in the Yucca Mountain region, structural geology of extensional terranes, morphotectonic phenomena, and Neogene and Quaternary tectonostratigraphy.

Mr. Alan R. Ramelli received his B.S. and M.S. degrees in geology from the University of Nevada, Reno. He has held a position as Research Geologist with the Nevada Bureau of Mines and Geology since 1986. He has been involved in research studies of active faulting and paleoseismology in the Basin and Range province and issues related to high-level nuclear waste storage since 1983. From 1983 to 1986, on a consulting basis, Alan conducted active-fault evaluations and reviews of environmental assessments and other documents for the Yucca Mountain, Deaf Smith, Hanford, and Davis Canyon proposed high-level nuclear waste storage sites. From 1986 to 1991, he conducted document reviews and original studies of the Yucca Mountain area, including planning of low-sun-angle aerial photography missions and mapping of faults and Quaternary geology, as part of studies conducted by the State of Nevada. From 1992 to present, under contract to the USGS, he has conducted paleoseismic studies, including exploratory trenching, of the Yucca Mountain area and has held primary responsibility for studies of the Solitario Canyon fault. Other recent projects involve paleoseismic studies, including exploratory trenching, of the Carson Range fault system in western Nevada and studies of the 1994 Double Spring Flat earthquake.

Dr. Albert M. Rogers is a Director of GeoRisk Associates, Inc., a geological hazards assessment corporation. Dr. Rogers has over 30 years of research experience, scientific publication, and professional project activities in both government and industry that are related to earthquake hazard assessment. He received a Ph.D. in geophysics in 1970 and a B.S. in 1965, both from Saint Louis University. He has conducted research related to earthquake hazard assessment in Nevada, Utah, the west Texas/southern New Mexico region, and the Pacific Northwest. Dr. Rogers was a Senior Scientist at Environmental Research Corporation and Technical Manager at EQE International. In these capacities, he was responsible for ground motion prediction research, site-specific probabilistic seismic hazard assessments of nuclear power plant sites in Finland and Slovokia, and at offshore oil platform sites in Venezuela, Trinidad, Java, and Sumatra. Dr. Rogers has conducted seismicity network studies to assess the seismic hazard to nuclear waste sites at the Waste Isolation Pilot Project in New Mexico, and at the proposed Yucca Mountain site in Nevada; he also led a study of induced seismicity at Lake Mead, Nevada. Dr. Rogers conducted a probabilistic seismic hazard assessment for DOE for the initial proposal for high-level nuclear waste site at NTS, termed the Retrievable Surface Storage Facility. He was an Expert Panel member for the first Tectonics Expert Judgment Elicitation Project for Yucca Mountain in 1991-92. His current research interest concerns earthquake strong motion prediction; this research focuses on prediction of the effect of geologic conditions on earthquake shaking levels, including current studies of vertical strong motion array data in Los Angeles. Dr. Rogers has had colloborative or advisory roles with scientists at the University of Roorkee, India, the Earthquake Engineering Research Institute in Skopje, Macedonia, the University of Costa Rica, and the Engineering Research Institute in Harbin, China. Dr. Rogers served as Branch Chief of the USGS Branch of Geologic Risk Assessment from 1984 to 1988 and during that time was also responsible, as Program Coordinator, for both the internal and external USGS Regional Earthquake Hazards Assessments Programs.

Dr. D. Burton Slemmons has published numerous papers, abstracts, and edited volumes dealing with neotectonics, earthquake hazard evaluation, and paleoseismicity. Dr. Slemmons received his Ph.D. in geology from the University of California, Berkeley in 1953. While a professor at the University of Nevada-Reno, he supervised more than two dozen theses of graduate students including studies in the Yucca Mountain region, covering Owens, Panamint, Saline, Death, Fish Lake, Amargosa, and Pahrump valleys. He assisted the Lawrence Livermore National Laboratory as a consultant in making high-level nuclear waste assessments of the 11 sites considered by the DOE. From 1985 to 1989, he directed the Yucca Mountain Project of the University of Nevada-Reno. He was one of the seven expert technical specialists selected by Geomatrix Consultants in the EPRI Earthquakes and Tectonics Expert Judgment Elicitation Project for the high-level waste repository at Yucca Mountain. He has consulted for Woodward-Clyde Federal Services in support of TRW from January 1992 to present on the Yucca Mountain Project, including activity as a member of the technical assessment team that prepared the report "Seismic Design Inputs for the Exploratory Studies Facility at Yucca Mountain" in 1994. During the past 25 years, he has also been an expert consultant for the U. S. Nuclear Regulatory Commission (NRC) or industry at more than 12 power plants in the U.S. Since 1984, he has been a technical expert for the International Atomic Energy Agency (IAEA) on missions to assess earthquake hazards at nuclear power plant sites in Armenia, Brazil, Croatia, and Indonesia.

Dr. Kenneth D. Smith obtained his Ph.D. from the University of Nevada in 1991. He holds bachelors degrees in geophysics from Boise State University and in geology from Indiana University. Dr. Smith has been involved in studies of the seismotectonics of the western Basin and Range province for over 10 years. During this time, he has had extensive experience in seismic network operations, portable seismic experiments, and seismic network data management for western Great Basin earthquake activity. Since 1992, these efforts have focused on evaluating the seismicity in and around the Yucca Mountain area. He was a primary author of a study of the source parameters and faulting behavior of the 1992 Little Skull Mountain earthquake and of a study of recent earthquake activity on the Rock Valley fault zone. He participated in the data collection for the Little Skull Mountain earthquake, the 1993 Rock Valley earthquake sequence, and the 1993 Non-Proliferation Experiment refraction survey. Other research activities in the western Basin and Range province have included determining the source parameters and complex faulting geometry of mainshock-aftershock sequences near Mammoth Lakes, California. Currently, he is involved in the operations and development of the digital upgrade for the southern Great Basin seismic network.

Dr. Robert B. Smith received his B.S. and M.S. in geology from Utah State University in 1960 and 1965, respectively. He received his Ph.D. in geophysics from the University of Utah in 1967. He is a Professor of Geophysics in the Department of Geology and Geophysics where he has worked since 1967. He has also served as a Visiting Professor at the Swiss Federal Institute of Technology and at Cambridge University. Most recently he has taught courses in tectonophysics/elastic waves, earthquake seismology, theoretical seismology, and inverse theory. He has supervised 53 graduate students. Dr. Smith's expertise includes mechanics and processes of earthquakes, the relationship between seismicity and active tectonics, wave propagation, seismicity of the Intermountain seismic belt, Global Positioning satellite measurements of crustal deformation, numerical modeling of fault and volcano processes, and analyses of earthquake hazards. In earthquake hazard, he has specifically worked on geometry and mechanics of normal faulting, scaling relations of surface fault parameters to magnitude, strong ground motion and attenuation of normal faulting earthquakes, and general seismotectonics. He has worked on seismic hazards projects in the Pacific Northwest, the Basin and Range province, and the Intermountain seismic belt. Dr. Smith has been Director and Associate Director of the University of Utah Seismograph Stations and he recently directed studies on the neotectonics of the Teton fault and paleoseismicity of the Intermountain seismic belt. His research and consulting work is supported by the NSF, the USGS National Earthquake Hazards Reduction and the Volcano Hazards programs, the National Park Service, as well as petroleum and mining companies. Smith has served as the President of the Seismology section of the American Geophysical Union, on the NSF Panel on Geophysics, on the NSF Advisory Board in Earth Sciences, on the Advisory Committee of the Southern California Earthquake Center, on the NRC Committee on Seismology, on the Executive Committee of the Seismological Society of America, and was a founding member of Incorporated Research Institutes of Seismology.

Since 1973, ***Dr. Frank H. (Bert) Swan*** has participated in and directed projects for seismic hazard evaluations for critical facilities, including more than 15 nuclear power plants, and other nuclear-related facilities. He has conducted fault studies in the eastern and western U.S., Alaska, Central and South America, North Africa, the Middle East, Southeast Asia, and

Eastern Europe. From 1978 to 1985, Dr. Swan was the principal investigator for a series of research projects funded by the USGS to investigate recurrence of moderate to-large-magnitude earthquakes associated with past surface faulting along the Wasatch fault zone in Utah and to make a probabilistic assessment of the potential ground motion levels for selected urban areas along the Wasatch Front. From 1987 to 1993, Dr. Swan was Project Manager and principal investigator for a detailed paleoseismic investigation of the Meers fault, Oklahoma for the NRC's Research Division. In 1992, he was a member of IAEA's Geological and Seismic Hazards Safety Review Mission for the Crimea Nuclear Power Plant in the former Soviet Union. In 1993, Dr. Swan provided technical review of a probabilistic seismic hazard analysis of the Krsko Nuclear Power Plant in the Republic of Slovenia. He was principal investigator for studies conducted at NTS in Nevada to assess the potential for surface faulting at the proposed site for the waste-handling facilities where high-level nuclear wastes will be received and packaged prior to their permanent burial in the proposed underground repository beneath Yucca Mountain. From 1990 to 1993, Dr. Swan was a member of the Nuclear Management and Resources Council's Ad Hoc Advisory Committee to review and propose revisions to the NRC guidelines for seismic and geological siting criteria for nuclear power plants. From 1990 to 1994, Dr. Swan was a member of the American Society of Civil Engineers Working Group on Dynamic Analysis and Design Considerations for High Level Nuclear Waste Repositories where he had the primary responsibility for preparing guidelines for investigations to assess the seismic potential of active faults and to assess the potential for fault rupture. Dr. Swan is currently a member of their Subcommittee on Design and Analysis for Seismic Fault Displacements.

Mr. James C. Yount has conducted research in tectonics with the USGS since 1975. He worked on the delineation of the seismotectonic framework of the Puget Sound region, including research on liquefaction phenomena in Seattle area, and identification of youthful faults in offshore regions of Puget Sound from 1975 to 1983. He has been investigating active faulting in the NTS area since 1983. These studies included mapping and trench description of faulting features along the Rock Valley fault system and mapping of youthful faulting features along the Solitario Canyon fault system, the Wahmonie fault, the Mine Mountain fault, and the Cane Spring fault system. Past studies related to neotectonics include investigation of faulting along the Mohawk Valley fault system, northeast California, mapping of ground rupture following the 1979 Imperial Valley earthquake, and mapping of ground rupture following the 1980 Mammoth earthquake. Mr. Yount obtained his B.S. from the University of Washington in 1968 and his M.S. from the University of Colorado in 1970.

BIOGRAPHIES OF GROUND MOTION EXPERTS

Dr. John G. Anderson is a seismologist and the Associate Director of the Seismological Laboratory at the University of Nevada, Reno. His undergraduate degree was earned in physics from Michigan State University. He received his Ph. D. degree in geophysics from Columbia University in 1976, where he specialized in seismology, and carried out research at the Lamont Doherty Earth Observatory. After earning his degree, Dr. Anderson held positions on the research faculty at the California Institute of Technology, the University of Southern California, and the University of California at San Diego. In 1988, he accepted a position of teaching and research at the University of Nevada. Dr. Anderson's research has included a broad range of studies relating to seismic hazards. He has installed strong motion accelerograph networks in the eastern U. S., in the Los Angeles metropolitan region, and in Guerrero, Mexico. He has carried out a wide variety of analyses of strong motion data: data processing, interpretation of the seismic source, describing and understanding site effects, developing attenuation relations, and preparing complete synthetic seismograms. These studies, combined, have helped to develop an understanding of the dominant effects that control the strong motion seismogram. Dr. Anderson has also been involved in research and applications of probabilistic seismic hazard analysis. One of the critical input parameters to hazard analysis is the seismic activity rate, and Dr. Anderson has studied how this rate can be developed from geological observations. Among other studies, he is currently involved in state-of-the-art studies in ground motion attenuation for the Southern California Earthquake Center. Dr. Anderson has published over 125 research articles and reports describing results of this research. He has some personal experience with the Yucca Mountain project originating from studies of the Little Skull Mountain aftershock sequence and site effects in Midway Valley and the region around the southeastern portion of the NTS. Professional relationships have included membership on two panels for the National Academy of Science (Seismic Risk, and Base Isolation), member and Chair of the Nevada Earthquake Safety Council, and Associate Director and Acting Director of the Seismological Laboratory of the University of Nevada. He has served on advisory panels organized by the USGS and the NSF and the National Earthquake Hazard Reduction Program.

Dr. David M. Boore is a geophysicist with the USGS. He earned his B.S. and M.S. degrees in geophysics from Stanford University and his Ph.D. in geophysics from M.I.T. He is internationally known for his work in developing empirical attenuation relations from strong ground motions. He has acted as an expert consultant to the Lawrence Livermore National Laboratory panels on seismic strong ground motion estimation in the eastern U. S. and on the Senior Seismic Hazard Analysis Committee (SSHAC). Dr. Boore currently also serves as a consultant to the DOE's Tank Seismic Expert Panel and on the Peer Review Panel for the NRC's Ground Motion Guidelines Project. He has chaired and acted as a member of the International Association of Seismology and Physics of the Earth's Interior Commission on Strong Motion Seismology, and is a member of the Panel on Wind and Seismic Effects for the U. S. - Japan Cooperative Program in Natural Resources. Dr. Boore has published over 130 papers, most of which deal with predicting ground motion.

Dr. Kenneth Campbell has professional experience in strong ground motion, seismic hazard evaluation, and engineering seismology, gained in his more than 20 years of research and consulting practice. He obtained his Ph.D. in 1977 in geotechnical and earthquake engineering from the University of California at Los Angeles. Since 1972, he has worked as an earthquake engineering consultant for several engineering firms and has served as a research civil engineer with the National Oceanic and Atmospheric Administration and the USGS. His experience lies in technical management, consulting, and research in the areas of engineering seismology, strong ground motion, seismic hazards evaluation, and geotechnical and lifeline earthquake engineering. He has directed projects throughout the world to develop deterministically and probabilistically defined seismic design and evaluation criteria for the nuclear, oil, utility, and construction industries. He has developed strong ground motion attenuation relationships from empirical data and has evaluated ground motions and seismic hazards for nuclear power plants, nuclear waste repositories, DOE facilities, and other critical facilities. Dr. Campbell has also served as an engineering seismology consultant to the NRC. He has participated on two expert panels for ground motion – for the NRC's seismic hazard estimates of the eastern U. S. and on the SSHAC. Currently, he is a member of the Earth Science Advisory Committee for the Savannah River site and is reviewing ground motion and seismic hazard estimates. He has estimated ground motions and provided testimony for the proposed low-level radioactive waste repository in Hudspeth County, Texas, which is regulated by the NRC. He participated on the seismic hazard