PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Verification of Probabilistic Seismic Hazard Analysis Computer Programs

Patricia Thomas and Ivan Wong
URS Corporation

Norman Abrahamson
Pacific Gas and Electric Company

PEER 2010/106
MAY 2010

Verification of Probabilistic Seismic Hazard Analysis Computer Programs

Patricia Thomas and Ivan Wong
Seismic Hazards Group
URS Corporation

Norman Abrahamson
Pacific Gas and Electric Company
Geosciences Department

PEER Report 2010/106
Pacific Earthquake Engineering Research Center
College of Engineering
University of California, Berkeley

May 2010

ABSTRACT

Probabilistic seismic hazard analysis (PSHA) has become a fundamental tool in assessing seismic hazards and for estimating seismic design and seismic safety evaluation of ground motions. It is used both on a site-specific basis for important and critical facilities and on a national scale for building codes. This report describes a project to test and verify the numerical approaches and software used in PSHA. The project was sponsored by the Pacific Earthquake Engineering Research (PEER) Center's Lifelines Program. A Working Group was organized and members tested their own computer codes in two sets of tests. Through several iterations, codes were tested and acceptable answers were established either through analytical solutions or as the consensus answer from the test case results. The verification tests are available to any PSHA code developer/user worldwide through this publication and the PEER website. The test cases will be used as a standard verification for all PSHA codes to be used in projects for the PEER Lifelines Program sponsors, which include the California Department of Transportation (Caltrans), the Pacific Gas & Electric Company (PG&E), and the California Energy Commission (CEC).

ACKNOWLEDGMENTS

This study was sponsored by the Pacific Earthquake Engineering Research Center's (PEER's) Program of Applied Earthquake Engineering Research of Lifelines Systems supported by the California Department of Transportation, the California Energy Commission, and the Pacific Gas and Electric Company. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the funding agencies.

Our thanks to Michael Riemer, Brian Chiou, Cliff Roblee, and Yousef Bozorgnia and the PEER Lifelines Program for their support of this project. Programming assistance was also provided by Ned Field and colleagues at the Southern California Earthquake Center (SCEC). This report was prepared with the assistance of Melinda Lee.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

In the past three decades, the approach to estimating earthquake ground shaking hazard, particularly to critical and important facilities, has slowly evolved from the traditional deterministic earthquake scenario analysis to probabilistic seismic hazard analysis (PSHA). A prime example is the very comprehensive PSHA that was performed to evaluate both ground shaking and fault displacement hazards at Yucca Mountain, the site of the nation's first nuclear waste repository (Stepp et al. 2001). The National Seismic Hazard Maps developed by the U.S. Geological Survey (USGS), which form the basis of building codes in the U.S. (e.g., International Building Code) are based on PSHA (Frankel et al. 1996; Petersen et al. 2008). Thus PSHA has become the primary tool in estimating seismic hazards in the U.S. and is gaining widespread use worldwide.

The results from PSHA also form the basis for (1) design ground motions specified in structural codes and standards (e.g., AASHTO for bridges); (2) site-specific design of important and critical facilities such as all U.S. Department of Energy facilities (e.g., national laboratories and Yucca Mountain); (3) site-specific design for nuclear power plants and interim nuclear waste storage sites; (4) safety analysis evaluations of important/critical facilities such as U.S. Bureau of Reclamation dams; (5) loss estimation to establish insurance rates; and many other uses. PSHA is now being used by federal and state agencies, which have traditionally used only a deterministic approach for estimating ground motions. Examples of such agencies are the U.S. Army Corps of Engineers and the California Division of Safety of Dams.

PSHA has its roots in the seminal paper by Cornell (1968). The objective in PSHA is to estimate the probability that a specified level of ground motion will be exceeded or to estimate the level of ground motions that will occur at a specified exceedance probability. PSHA integrates hazard from all significant seismic sources and incorporates the frequency of earthquakes from each seismic source. A significant aspect of PSHA is that it allows for the explicit treatment of uncertainty in the inputs. The uncertainties can be quite large in characterizing seismic sources and ground motion attenuation. For a comprehensive discussion of PSHA, we refer the reader to the EERI monograph *Seismic Hazard and Risk Analysis* by McGuire (2004) or the Senior Seismic Hazard Advisory Committee (1997) report.

Despite the relatively widespread use both nationally and internationally of PSHA, only a few publicly available and proprietary PSHA computer codes have been developed. In large part, this is because PSHA calculations are still being done by a relatively small proportion of the professional community. Because of the importance of PSHA in seismic design, the Pacific Earthquake Engineering Research (PEER) Center's Lifelines Program sponsored a Working Group to verify both the numerical approaches and computer software used in PSHA. To our knowledge, this is the first ever comprehensive, organized, and structured verification of PSHA software. This project is one of several projects sponsored by the PEER Center's Lifelines Program to improve tools in seismic hazard estimation. The goal of the Lifelines Program is to increase the safety and reliability of utility and transportation systems in earthquakes through better characterization of the hazards and improved performance of system components.

The objective of the project was to develop a set of standard exercises that can be used by current and future PSHA software developers to validate their codes. The verification process will also provide the means for the PEER Lifelines Program sponsors (the California Department of Transportation, the Pacific Gas and Electric Company, and the California Energy Commission) to ensure that work done for them by others, including consultants, is done using qualified software.

The following describes the two test case sets developed for verification, the final results for Test Case Set 1, and the sample results for Test Case Set 2.

2 Approach

The PSHA Validation Project was managed by Ivan Wong and Patricia Thomas (co-Principal Investigators) with assistance from Norm Abrahamson. Members of the Working Group consisted of prominent code developers from government agencies and engineering and risk analysis and management services firms. The members of the Working Group and their computer programs included:

Member	Affiliation	Program
Tianqing Cao	California Geological Survey	haz02
Ned Field	U.S. Geological Survey	OpenSHA
Steve Harmsen	U.S. Geological Survey	hazFX v.3f, hazgridX v 3.f, fltrate.peer.f
Roland LaForge	U.S. Bureau of Reclamation	faultsource_20, mrs 3.1
Robin McGuire	Risk Engineering	EZ-FRISK
Andres Mendez	Impact Forecasting	EQ-Elements
Badie Rowshandel	California Geological Survey	HAZDIR
Jean Savy	Lawrence Livermore National Laboratory	ALEAS
Mark Stirling	New Zealand Institute of Geological and Nuclear Sciences	NEWHAZ
Phalkun Tan	GeoPentech	GP-Haz
Gabriel Toro	Risk Engineering	FRISK88M Version 2.05
Bob Youngs	Geomatrix Consultants	XCD52, HAZ50, TREE50

The Working Group tested both publicly available codes as well as proprietary codes that have been used extensively in hazard evaluation in the U.S. and worldwide. Basic attributes of the various codes are listed in Table 2.1. Three publicly available codes were tested: EZ-FRISK developed by Risk Engineering, Inc.; HAZ38 developed by Norm Abrahamson; and OpenSHA developed by the U.S. Geological Survey. The former is a widely used code both in the U.S. and internationally. HAZ38 was tested by the PIs. OpenSHA was tested by Ned Field. The basic codes used in the development of the U.S. Geological Survey's National Hazard Maps were tested by Steve Harmsen. The project began in November 2001. A paper that described the early stages of the project was published in 2004 (Wong et al. 2004).

Table 2.1a PSHA code properties

Code	Numerical Model	Truncation Of Ground Motion	Rupture Plane Modeling	Rupture Length & Width Modeling
FRISK88M Version 2.0 G. Toro	Polynomial (26.2.17 of Abramowitz & Stegun)	# Standard Deviations Max. Ground Motion	Horizontal location & hypocentral depth is uniformly distributed. Rupture confined to fault plane.	User inputs Log L = a+bM and std. dev. User-specified std dev Width = ratio * length User specified ratio Length & width not to exceed fault plane
EZ-FRISK R. McGuire	Polynomial (26.2.17 of Abramowitz & Stegun)	# Standard Deviations Max. Ground Motion	Horizontal location & hypocentral depth is uniformly distributed. Rupture confined to fault plane.	User inputs Log L = a+bM and std. dev. User-specified std. dev. Width = ratio * length. User specified ratio. Length & width not to exceed fault plane.
XDC52, HAZ50, TREE50 B. Youngs	Series expansion	# Standard Deviations	Uniform distribution along length. User specified hypocentral depth distribution. For straight-line fault, analytical distance distribution computed. For segmented fault, numerical distribution using 1 km steps. Rupture confined to fault plane	Rupture area specified by log-linear relationship with magnitude. Aspect ratio defined by log linear relationship, 1:1 for M 4, user specified for M 7. Aleatory variability not modeled.
HazFX v3.f, hazgridX v3.f, filtrate.peer.f A. Frankel S. Harmsen	Call to the error function	# Standard Deviations. For CEUS relations, can also truncate at maximum ground motion.	Rupture floats along strike. Rupture confined to fault plane.	For gridded seismicity code, use W&C Magnitude-Length relations. For fault code, rupture always extends from top to bottom (Mmin=6.5). No variability in rupture length or width.
ALEAS J. Savy	Abramowitz polynomial approximation	# Standard Deviations Max. Ground Motion	Monte-Carlo simulation with model of initiation point based on probability distributions of depth and location along the fault. User notified if rupture extends off fault plane.	Rupture area is simulated from set of weighted area-magnitude relations. Area is positioned using distributions on depth and location of initiation point.
EQ-Elements A. Mendez	Discrete numerical integration of equation	# Standard Deviations Max. Ground Motion (Code uses both at the same time.)	Rupture centroid is uniformly distributed along length. Depth of centroid is a function of the magnitude.	Log10(A)=m-4.2 (USGS 99-517) Use Abrahamson (written communication 1992) to determine width and length.

Table 2.1a—*Continued*

Code	Numerical Model	Truncation Of Ground Motion	Rupture Plane Modeling	Rupture Length & Width Modeling
GP-Haz P. Tan	Series approximation	# Standard Deviations	Rupture location is discretized uniformly on fault plane. The distance between 2 discrete points can be specified. Rupture location is truncated such that ½ the dimension of the plane does not extend beyond the ends of the fault.	Rupture area calculated first from W&C. Next, rupture length is calculated from W&C. Width is calculated as the ratio of area to length. No aleatory variability is included.
NEWHAZ M. Stirling	Call to error function (For PC code, this uses polynomial expression 7.1.26 in Abramowitz & Stegun.)	# Standard Deviations	Rupture extends to the ends of the fault segment (characteristic model for all faults). Ruptures can overlap by calculating recurrence parameters so that they balance the slip rate. No rupture extends beyond the ends of the fault.	No aleatory variability in length or width. Epistemic uncertainty by modeling overlapping ruptures (that balance the slip rate).
faultsource-20 mrs 3.1 R. LaForge	Discrete numerical integration directly from the equation	# Standard Deviations	EQs are modeled as square (or any other aspect ratio) rupture areas. As many areas as possible are sequenced on plane starting in one corner. Pattern can be shifted along strike and dip as many times as necessary to achieve stable results	The normal distribution of rupture area as a function of magnitude (W&C) can be incorporated.
OpenSHA N. Field	Gamma Series	# Standard Deviations Maximum ground motion	Rupture floats along or down dip. Rupture constrained to fault plane.	Uses M(A) relationships. Aleatory variability can be accommodated.
HAZDIR B. Rowshandel	Direct numerical integration	Standard Deviations	Rupture is confined to fault surface. Rupture floats along strike and across width. Homogeneous rupture with unidirectional directivity effects. Heterogeneous rupture based on asperity and slip distribution. Single hypocenter and random hypocenter with specified distribution are handled.	Rupture area and length are calculated from magnitude. Rupture width is calculated from magnitude or using aspect ratio. Aleatory variability can be included.

Table 2.1b PSHA code properties

Code	Magnitude Density Functions	Area Source Modeling
FRISK88M Version 2.0 G. Toro	AREAS: Truncated exponential, modified exponential (Youngs et al. 1987). FAULTS: Truncated exponential, modified exponential (Youngs et al. 1987), characteristic (user-specified width and ratio between exponential and characteristic portion; rate is specified as total recurrence rate or slip rate). Can model boxcar distribution as a special case of characteristic or exponential distributions.	Point source is default. Hypocenter depth fixed or random, with user-specified distribution; can also include effect of rupture width on depth distribution. Effect of rupture length for modeled background sources can be by randomizing rupture orientation or calculating distance to rupture or using analytical approximation.
EZ-FRISK R. McGuire	AREAS: Truncated exponential, modified AREAS: Truncated exponential, modified exponential (Youngs et al. 1987). FAULTS: Truncated exponential, modified exponential (Youngs et al. 1987), characteristic (user-specified width and ratio between exponential and characteristic portion; rate is specified as total recurrence rate or slip rate). Can model boxcar distribution as a special case of characteristic or exponential distributions.	Point source is default. Hypocenter depth fixed or random, with user-specified distribution; can also include effect of rupture width on depth distribution. Effect of rupture length for modeled background sources can be by randomizing rupture orientation or calculating distance to rupture or using analytical approximation.
XDC52, HAZ50, TREE50 B. Youngs	Truncated exponential Modified truncated exponential (Youngs et al. 1987) Characteristic with variable width (Youngs and Coppersmith) Separate exponential characteristic components with user specified rates Discrete frequencies for individual magnitude increments Real time probabilities for specified time period	Area sources are modeled using closely spaced faults.
HazFX v3.f, hazgridX v3.f, filtrate.peer.f A. Frankel S. Harmsen	For gridded seismicity code, use truncated exponential applied to density function. For fault code, also have a maximum magnitude model.	For gridded seismicity code, above M=6.0 use vertical faults (line sources) with random strike centered on each grid point with fixed depth. For M<6.0 use point sources.
ALEAS J. Savy	Truncated exponential Characteristic models: Standard Youngs and Coppersmith Segmented model of the types developed by WG99. (Input slip rates, probabilities of segmentations, segment lengths, with uncertainty on their endings & lengths). Completely empirical occurrence curve defined at magnitude points, with uncertainty.	Area sources modeled as horizontal planes.
EQ-Elements A. Mendez	Truncated exponential Characteristic	Area sources are modeled as faults. When a-value, b, & Mmax known over a spatial grid, faults are randomly generated over grid. When input is "complete" EQ catalog, a-value is calculated over a spatial grid through the use of an elliptical spatial weighting function applied to each event. EQ events are generated as in (a). When area is polygon, the area is filled with faults such that the seismicity follows the input distributions. "Hard" (all EQs in polygon) and "Soft" (EQs can rupture beyond polygon edge). Can enter preferred azimuth.

Table 2.1b—*Continued*

Code	Magnitude Density Functions	Area Source Modeling
GP-Haz P. Tan	Truncated exponential (truncation applied to density function). Characteristic (Youngs and Coppersmith)	Area sources are modeled as line sources (multi-linear lines on surface) and multi-planar sources (planar sources defined by 3 multi-linear lines).
NEWHAZ M. Stirling	Truncated exponential (truncation applied to density function). Characteristic (assumes one EQ size that is proportional to dimensions of the fault).	Area sources are modeled as a series of point sources, with the ability to use an adaptation of the Frankel Gaussian smoothing function.
faultsource-20 mrs 3.1 R. LaForge	Exponential Characteristic Maximum Moment	Area sources are modeled as point sources with fixed grid spacing. Depths are modeled as a triangular distribution with peak and maximum depth specified, with a near-surface modification.
N. Field	Dirac delta. Gaussian with optional truncation. Truncated exponential (truncation on density function).	Area sources are modeled as grid points on a horizontal plane.
HAZDIR B. Rowshandel	Truncated exponential, Gaussian, characteristic (single magnitude), Characteristic (Youngs and Coppersmith), Characteristic with aleatory uncertainty on M_{ch} modeled using normal probability density function.	Area sources are modeled as point sources with fixed grid spacing distributed over any shape area. Horizontal source with uniform depth and dipping source with variable depth. Capable of Gaussian smoothing, as used in the USGS National Hazard maps.

2.1 VERIFICATION PROCESS

The focus of the project was the numerical verification of the codes, and analysis and comparison of their various features. The verification exercises consisted of two sets of cases that tested fundamental aspects of the codes including how they modeled (1) faults, areal sources, and complex fault geometries, (2) recurrence models and rates, and (3) attenuation relationships and their uncertainties. The test cases ranged from the simplest to more sophisticated. The simplest cases have analytical solutions, but the more complex cases do not. “Acceptable” answers to the test cases were defined either through comparisons with the analytical solutions or the means over all results.

The test case sets were developed by the PIs and were distributed to each member of the Working Group. Each member initially ran the test cases and sent their results back to the PIs. The results were compiled for the whole Working Group and sent back to each participant without identifying the names of the codes except for their own code. This initial feedback allowed for each code developer to identify numerical errors, errors in interpretations, or limitations in their codes and the opportunity to correct them. In some cases, this resulted in modifications of the codes. For each test case set, the above steps were followed and a workshop was held to discuss the group results, to identify discrepancies and the reasons for them, particularly if differences were due to differences in assumptions, numerical solutions, and hence features of the codes. Recommendations of minimum standards for meeting the benchmark results (e.g., 10% in probability level) were also defined to qualify the hazard codes.

A total of five workshops were held by the Working Group to discuss and evaluate the results of the two test case sets. Several iterations of running the test cases were required by the Working Group members. In some cases, test cases required re-running because of misinterpretations of the tests as well as software errors. Because of the extended duration of the project, schedule conflicts and change in affiliations prevented some of the Working Group members (Cao, Harmsen, Savy, and Stirling) from completing the test cases.

The major differences between the individual results, however, were due to differences in numerical approaches in the codes. For example, possibly the most significant difference among the Working Group members was the approach in modeling rupture areas for events smaller than the total fault area. In particular, the way the rupture area is moved along the length and width of a fault led to significant differences in the PSHA results. Some developers allowed the rupture area to extend beyond the fault. Some pushed the rupture area back onto the fault, while others tapered the slip at the edges. Some of the large differences were found to be an initial lack of clearly defined test cases (i.e., artificially set sigma to zero, not truncate sigma at zero). Other issues encountered in the test cases were the implementation of hanging wall/footwall factor in the Abrahamson and Silva (1997) attenuation relationship, the modeling of nonplanar faults with depth, and the lower limit of integration of the hazard (e.g., Mmin or negative infinity). The magnitude step size used in the test cases also led to differences in the test cases.

2.2 GENERAL PSHA THEORY

The standard PSHA approach is based on the model developed principally by Cornell (1968). The occurrence of earthquakes on a fault is assumed to be a Poisson process. The Poisson model is widely used and is a reasonable assumption in regions where data are sufficient to provide only an estimate of average recurrence rate (Cornell 1968). When there are sufficient data to permit a real-time estimate of the occurrence of earthquakes, the probability of exceeding a given value can be modeled as an equivalent Poisson process in which a variable average recurrence rate is assumed. The occurrence of ground motions at the site in excess of a specified level is also a Poisson process if (1) the occurrence of earthquakes is a Poisson process and (2) the probability that any one event will result in ground motions at the site in excess of a specified level is independent of the occurrence of other events.

The probability that a ground motion parameter "Z" exceeds a specified value "z" in a time period "t" is given by:

$$p(Z > z) = 1 - e^{-\nu(z) \bullet t} \tag{2.1}$$

where $\nu(z)$ is the annual mean number (or rate) of events in which Z exceeds z. It should be noted that the assumption of a Poisson process for the number of events is not critical. This is because the mean number of events in time t, $\nu(z) \bullet t$, can be shown to be a close upper bound on the probability $p(Z > z)$ for small probabilities (less than 0.10) that generally are of interest for engineering applications. The annual mean number of events is obtained by summing the contributions from all sources, that is:

$$\nu(z) = \sum_{n} \nu_n(z) \tag{2.2}$$

where $\nu_n(z)$ is the annual mean number (or rate) of events on source n for which Z exceeds z at the site. The parameter $\nu_n(z)$ is given by the expression:

$$\nu_n(z) = \sum_{i}\sum_{j} ß_n(m_i) \bullet p(R{=}r_j|m_i) \bullet p(Z{>}z|m_i,r_j) \tag{2.3}$$

where:

$ß_n(m_i)$	=	annual mean rate of recurrence of earthquakes of magnitude increment m_i on source n;
$p(R{=}r_j|m_i)$	=	probability that given the occurrence of an earthquake of magnitude m_i on source n, r_j is the closest distance increment from the rupture surface to the site;
$p(Z > z|m_i,r_j)$	=	probability that given an earthquake of magnitude m_i at a distance of r_j, the ground motion exceeds the specified level z.

3 Test Cases and Results

Two sets of test cases were developed to evaluate elements of the PSHA codes. The objective of Test Case Set 1 was to test some basic elements of the codes, including how rupture areas were modeled on a fault plane, how recurrence models were used, how area sources were modeled, and how the standard deviations (sigma) in attenuation relationships were incorporated into the hazard calculations.

The purpose of Test Case Set 2 was to test more sophisticated elements of the codes such as the modeling of non-planar faults, listric faults, and the intraslab regions of subduction zones (Wadati-Benioff zones), multiple seismic sources, recurrence intervals as implemented with recurrence models, use of logic trees, computation of fractiles, and deaggregation.

The solutions to Test Case Set 1 are shown in the Appendix. The solutions to test Case Set 2 are not provided because consensus results were not reached due to schedule constraints (Section 3.2).

3.1 TEST CASE SET 1

Test Case 1 underwent three revisions due to not readily explainable differences in results in the first two versions. This third version was chosen to focus on the simple test cases of Set 1. The solutions have been calculated by hand and with Microsoft Excel for some of the test cases. To aid in the process, magnitude probability functions and distance probability functions have been provided for many of the cases and sites. Figure 3.1 illustrates the fault and site geometry. Site and source coordinates are provided in Appendix A.

The following were the instructions to the Working Group Members:

Please provide mean hazard results (probability of exceedance) for peak horizontal acceleration (PGA) defined at 0.001, 0.01, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.7, 0.8, 0.9, and 1.0 g. Assume a Poisson model when converting rates to annual probabilities of exceedance. Hand-calculated solutions are provided in Appendix A for the following test cases: 1, 2, 4, 5, 6, 7, and 9b. For tests cases and sites without hand-calculated solutions, mean results from the group of participants is provided in Appendix A.

Use 16.05 (not 16.1) in the equation $\log M_o = 16.05 + 1.5\mathbf{M}$

Use $3\text{x}10^{11}$ dyne/cm^2

Use a magnitude integration step size small enough to define the specified magnitude density function. The bin size for magnitude integration should be defined such that the M_{min} is at the lower edge of a bin, not in the center (i.e., If your magnitude step size is 0.01, one magnitude bin should be from **M** 5.0 to 5.01)

When integrating over the magnitude density function, integrate from zero (not M_{min})

Use uniform slip with tapered edges. Downdip and along-strike integration step size should be small enough to produce uniform rupture location. Do not allow rupture off the ends of fault.

Maintain the aspect ratio defined until maximum width is reached, then increase length (conservation of area at the expense of aspect ratio)

Sigma = 0 for the attenuation relationship implies that the sigma in the relationship is artificially set to zero, not that the sigma is truncated.

Note that equation for ln(y) in Table 3.1 of Sadigh *et al*. (1997) has a typo in the third term. It should read C3*(8.5-M)^2.5 to match equation 2.2.

Rupture dimension relationships:

$\text{Log}(A) = \mathbf{M} - 4$ $\quad \sigma_A=0.25$

$\text{Log}(W) = 0.5*\mathbf{M} - 2.15$ $\quad \sigma_W=0.15$

$\text{Log}(L) = 0.5*\mathbf{M} - 1.85$ $\quad \sigma_L=0.20$

Aspect Ratio = 2

Note: Sigma for all rupture dimension relationships should be set to zero for all cases except 3a–g.

For all faults, the slip rate is 2 mm/year, b-value = 0.9

For the area source, number of events per year of M_{min} and greater ($\mathbf{M} \geq 5$) is 0.0395 for the whole area, b-value =0.9, and M_{max} = 6½.

The following test cases are also summarized in Table 3.1.

Table 3.1 Test cases set 1

Name	Description	Source	Magnitude-Density Function[1,2]	Attenuation Relation	Rupture Dimension Relationships[3,4,5,6]
Set 1 Case 1	Single rupture of entire fault plane. Tests distance, rate, and attenuation calculations.	Fault 1 (vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.5	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 2	Single rupture smaller than fault plane. Tests uniform slip and edge effects.	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 3	Single rupture smaller than fault plane, including variation of rupture plane dimensions. Tests uniform slip and edge effects, variability of rupture areas.	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0.25$ Log (W)=0.5*M-2.15; $\sigma_W = 0.15$ Log (L)=0.5*M-1.85; $\sigma_L = 0.20$
Set 1 Case 4	Single rupture smaller than fault plane on dipping fault.	Fault 2(reverse 60°) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 5	Truncated exponential model.	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Truncated exponential model, M_{max} = 6.5 M_{min}=5	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 6	Truncated normal model.	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Truncated normal model, M_{char} = 6.2, M_{max} = 6.5, sigma=.25 M_{min}=5	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 7	Characteristic model (Youngs & Coppersmith 1985)	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Characteristic model, M_{char} = 6.2, M_{max} = 6.45 M_{min}=5	Sadigh *et al.*(1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 8a	Single rupture smaller than fault plane. (Repeat of case 2 with gm variability untruncated).	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock Do not truncate sigma	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$

Table 3.1—*Continued*

Name	Description	Source	Magnitude-Density Function[1,2]	Attenuation Relation	Rupture Dimension Relationships[3,4,5,6]
Set 1 Case 8b	Single rupture smaller than fault plane. (Repeat of case 2 with gm variability truncated at 2 std. dev.).	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock Truncate sigma at 2 std.dev.	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 8c	Single rupture smaller than fault plane. (Repeat of case 2 with gm variability truncated at 3 std.dev.)	Fault 1(vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al*. (1997), rock Truncate sigma at 3 std.dev.	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 9a	Single rupture smaller than fault plane on dipping fault with gm truncated at 3 std. dev.	Fault 2(reverse 60°) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Sadigh *et al.*(1997), rock Truncate sigma at 3 std.dev.	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 9b	Single rupture smaller than fault plane on dipping fault using AS 97 gm, no gm variability.	Fault 2(reverse 60°) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Abrahamson & Silva (1997), rock $\sigma = 0$	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 9c	Single rupture smaller than fault plane on dipping fault using Campbell 1997 and gm truncated at 3 std. dev.	Fault 2(reverse 60°) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.0	Campbell (1997), soft rock, depth to basement rock = 2km, depth to seismogenic zone=3km Truncate sigma at 3 std.dev., use amplitude dependent sigma	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$
Set 1 Case 10	Area Source with fixed depth of 5 km.	Area 1 $M_w \geq 0.0395$ b-value=0.9	Truncated Exponential, M_{max}=6.5 M_{min}=5	Sadigh *et al.* (1997), rock $\sigma = 0$	Use 1 km grid spacing of point sources or small faults to simulate uniform distribution.
Set 1 Case 11	Volume Source with depth of 5 km to 10 km.	Area 1 $M_w \geq 0.0395$ b-value=0.9	Truncated Exponential, M_{max}=6.5 M_{min}=5	Sadigh *et al.*(1997), rock $\sigma = 0$	Use 1 km grid spacing of point sources or small faults to simulate uniform distribution.
Set 1 Case 12	Single rupture of entire fault plane. Adding ground motion variability to Case 1.	Fault 1 (vertical SS) b-value=0.9 slip rate=2mm/yr	Delta Function at M 6.5	Sadigh *et al.*(1997), rock Truncate sigma at 3 std.dev	Log (A)=M-4; $\sigma_A = 0$ Log (W)=0.5*M-2.15; $\sigma_W = 0$ Log (L)=0.5*M-1.85; $\sigma_L = 0$

1 Integration over magnitude zero.
2 Use magnitude integration step size as small as necessary to model magnitude density function.
3 For all cases, uniform slip with tapered slip at edges (see Fig. 3.2).
4 No ruptures are to extend beyond the edge of the fault plane.
5 Aspect Ratio to be maintained until maximum width is reached, then increase length (conserve area at the expense of aspect ratio).
6 Downdip and along strike integration step size should be as small as necessary for uniform rupture location.

<u>Case 1</u>

Purpose: A single rupture of the entire fault plane will test the code calculation of distance, fault activity rate, and attenuation relation without variability.

Single-magnitude event (**M** 6.5) on Fault 1 that ruptures entire fault plane. Use Sadigh *et al*. (1997), rock, sigma = 0. Calculate the hazard for the seven sites shown in Figure 3.1.

Results

Test Case 1 is designed to test the code computation of fault distance, fault activity rate, and median ground motion predicted by the Sadigh *et al*. (1997), rock, for a given magnitude and distance. With a single-magnitude event (delta function of **M** 6.5) that ruptures the entire fault, the fault activity rate of 2.853E-3 is easily computed using the slip rate (2 mm/year) and fault area (300 km^2). Due to the lack of variability in the ground motion and in the distance to the rupture plane for each site, the resulting hazard curve is a horizontal line at the fault activity rate extending to the ground motion value predicted for the magnitude and distance. Table 3.2 provides the median ground motion for each site. The results from all codes tested matched the analytical solution (Figs. 3.2–3.8).

Table 3.2 Median PGA values at sites 1–7

Site	Distance (km)	PGA for M 6.5 (g)
1	0	0.7717
2	10	0.3123
3	50	0.0497
4	0	0.7717
5	10	0.3123
6	0	0.7717
7	10	0.3123

<u>Case 2</u>

Purpose: A single rupture smaller than the fault plane tests uniform slip and edge effects.

Single-magnitude event (**M** 6.0) on Fault 1 with one size rupture plane (smaller than total fault plane area) as defined using the rupture area (RA), rupture width (RW), rupture length (RL) and/or aspect ratio relationships given below ($\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$). Use Sadigh *et al*. (1997), rock, sigma = 0. Calculate the hazard for the seven sites shown in Figure 3.1.

Results

Test Case 2 is designed to test a code's computation of rupture area, distribution of slip, and distance to rupture. Variability of RA dimensions and ground motion was set to zero to simplify the test case. The initial results from the codes tested showed significant differences. Figure 3.9 shows an early set of results for Site 1, which is located on the trace of the fault at the midpoint along the strike. Some codes initially provided different results for Sites 4 and 6, which are located at the ends of the fault. An examination of the results and discussion among participants determined that modeling of the rupture on the fault plane, especially near the fault edges, differed among code developers. These differences in approach led to significant differences in hazard for this simple test case. The Working Group decided to adopt a recommended approach for the rupture model: uniform slip which tapers at the fault edges. This can be achieved by uniformly distributing the rupture plane from one edge of the fault to the other end both along the strike and the down-dip width. No ruptures are allowed to extend beyond the edges of the fault. Hazard near the ends is sensitive to the step-size used to move the rupture. With the recommended approach, the codes tested were able to approximate the analytical solution closely. Figures 3.10 to 3.16 show the results for the seven sites.

Case 3

Purpose: A single rupture smaller than the fault plane with variability in the rupture dimension relationships included tests of the uniform slip and edge effects with variability of the rupture area, the width and the length.

Single-magnitude event (**M** 6.0) on Fault 1 with rupture planes as defined using the RA, RW, RL and/or aspect ratio relationships given below (include sigma in these relationships). Maintain the aspect ratio defined until maximum width is reached, then increase length (conservation of area at the expense of aspect ratio.) Use Sadigh *et al*. (1997), rock, sigma = 0. Calculate the hazard for the seven sites shown in Figure 3.1.

Results

Test Case 3 builds directly on Case 2. The only change is the inclusion of variability in the rupture dimension relations. The rupture dimension equations were chosen such that the median rupture length and width would not be sensitive to the computation approach. Some of the codes compute RA based on magnitude then maintain a constant aspect ratio. Other codes compute RA and width based on magnitude and back out the rupture length. However, the different approaches to incorporating the variability and computing the rupture dimensions will provide different hazard results. The variation of hazard results provides an example of the sensitivity to this parameter. Note that the variability in the rupture dimension equations is not always incorporated in standard PSHAs. The results for all sites are shown in Figures 3.17–3.23.

Case 4

Purpose: This case is a repeat of Case 2 using a dipping fault (Fault 2). It tests the calculation of distance to a dipping fault.

Single-magnitude event (**M** 6.0) on Fault 2 with one size rupture plane (smaller than total fault plane area) as defined using the RA, RW, RL and/or aspect ratio relationships given above ($\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$). Use Sadigh *et al*. (1997), rock, sigma = 0. Calculate the hazard for the seven sites shown in Figure 3.1.

Results

Test Case 4 is intended to further test the geometric modeling of faults. It is a slight variation of Test Case 2. In this case, a single size rupture smaller than the full fault plane occurs on a buried dipping fault. With variability in ground motion and rupture dimensions set to zero, the hazard is a function only of the fault activity rate (calculated from the magnitude, slip rate and fault area) and distance to the rupture. The solutions computed by hand and Microsoft Excel are compared to the results for Sites 1, 2, and 7. As with Test Case 2, initial results showed large variation due to variation in approaches for distribution of rupture plane on the fault plane, especially near the edges. Figures 3.24 and 3.25 are the initial results for sites on the ends of the fault (Sites 4 and 6, respectively.) After modifications to model slip that tapers at the edges, all results compare well with the hand solutions, with the exception of one code for Site 7, which is on the footwall (Figs. 3.26–3.32). In addition, results from these codes are all tightly grouped. These results indicate that the geometric modeling of dipping faults and movement of ruptures on the fault plane are consistent among the codes.

Case 5

Purpose: Tests calculation of the truncated exponential model.

Calculate the hazard for all seven sites due to rupture of Fault 1 using the truncated exponential model (M_{max} 6.5 and M_{min} 5.0) and Sadigh *et al*. (1997), rock, sigma = 0. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Results

Test Case 5 is intended to test one magnitude-frequency distribution, specifically the truncated exponential model. This model is used extensively in realistic hazard analyses. The initial results pointed toward a difference in approach for calculating the fault activity rate using the truncated exponential magnitude distribution model. As seen in Figure 3.33, the initial hazard results could be grouped into two sets. The difference is due to whether the integration over magnitude is done from the minimum magnitude or zero. Participants were then asked to modify their codes to integrate from zero. The results for all sites are shown in Figures 3.34–3.40. The solutions were computed by hand with the assistance of Microsoft Excel for Sites 4, 5, and 6, for which the geometries provide simple distance to rupture distributions. Hazard results from all codes compare well with the hand solutions, and are tightly grouped for the sites without hand solutions.

Case 6

Purpose: Tests the truncated normal model.

Calculate the hazard for all 7 sites due to the rupture of Fault 1 using the truncated normal model (M_{char} 6.2, M_{max} 6.5, sigma 0.25 and M_{min} 5.0) and Sadigh *et al.* (1997), rock, sigma 0. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Results

Test Case 6 is intended to test the truncated normal magnitude distribution model. Figures 3.41 to 3.47 show the results for all sites. As with Test Case 5, the results from all codes compare well with the hand solutions, and are tightly grouped for the sites without hand solutions.

Case 7

Purpose: Tests the characteristic model.

Calculate the hazard for all 7 sites due to the rupture of Fault 1 using the characteristic model (Youngs and Coppersmith [1985] M_{char} 6.2, M_{max} 6.45, and M_{min} 5.0) and Sadigh *et al.* (1997), rock, sigma 0. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of rupture planes.

Results

Test Case 7 is intended to test the characteristic magnitude frequency distribution, which is used extensively in modern PSHAs. Similar to Test Case 5, which tests the exponential model, early results showed differences in calculating the fault activity rate. The initial results for Site 6 are shown in Figure 3.48. Note the spread in hazard at very low ground motions. The final results show consistency between all codes (Figs. 3.49–3.55).

<u>Case 8</u>

Purpose: This is a repeat of Case 2 with ground motion variability included as defined by the attenuation relationship. The case is run with ground motion variability untruncated, truncated at 2 standard deviations, and truncated at 3 standard deviations.

Calculate the hazard for all seven sites due to a single-magnitude event (**M** 6.0) on Fault 1 using Sadigh *et al*. (1997), rock, sigma untruncated, and truncated at two and three standard deviations. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Results

Test Case 8 is an extension of Case 2 in order to test the addition of aleatory variability in the ground motion prediction equation. The case was analyzed using untruncated variability and variability truncated at two and three standard deviations. The hazard results from all codes are tightly grouped. Figures 3.56 to 3.62 show the results for untruncated ground motion variability. The hazard results for cases with ground motion variability truncated at two and three standard deviations are shown in Figures 3.63–3.69 and Figures 3.70–3.76, respectively.

<u>Case 9</u>

Purpose: A single rupture smaller than the fault plane on a dipping fault testing three common attenuation relationships.

Calculate the hazard for all seven sites due to a single-magnitude event (**M** 6.0) on Fault 2 using the following three attenuation relationships

(9a) Sadigh *et al*. (1997), rock, sigma truncated at 3 standard deviations

(9b) Abrahamson and Silva (1997), rock, sigma = 0

(9c) Campbell (1997), soft rock, depth to basement rock = 2 km, depth to seismogenic zone = 3 km, sigma truncated at 3 standard deviations

Compute the results for the attenuation relationships individually. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Note for Abrahamson and Silva (1997), include the style of faulting factor (F=1 for reverse fault) and the hanging wall factor. As defined, the hanging wall factor applies to only Site 2. HW = 1 for Sites 1, 2, 3, 4, and 6. However, fHW(Rrup) = 0 for Sites 1, 4, and 6 (Rrup < 4) as well as Site 3 (Rrup > 25). HW = 0 for Site 5 (off edge) and Site 7 (on footwall).

Also note that the Abrahamson and Silva (1997) formula for f3(M), Eq. 6, p.106 contains an error. For **M** between 5.8 and c1, the fraction $[(a_6-a_5)/(c_1-5.8)]$ should be multiplied by (**M**-5.8).

Results

Test Case 9a is an extension of Test Case 4. The variability in the ground motion attenuation relation is included and truncated at three sigma. The hazard results are shown in Figures 3.77–3.83. Hand solutions were not computed; however, there is consistency in the results from all codes.

Test Case 9b uses an attenuation relation that includes hanging wall effects. The variability in the ground motion is not included so as to allow for easier hand solution. The solutions are provided for Sites 1, 2, and 7. The hazard results for all sites are shown in Figures 3.84–3.90. For sites on the ends of the surface projection of the fault, Sites 4 and 6, there is one outlier (Figs. 3.87 and 3.89). The results from Site 1 also show some variation among codes, the source of which has not been determined.

Test Case 9c tests the implementation of the Campbell (1997) attenuation relation for soft rock. The results are presented in Figures 3.91–3.97. The hazard results are clustered into two groups. This is due to the use of different estimates of variability in the ground motion attenuation relation. Campbell (1997) provides two estimates of variability, one as a function of magnitude and one as a function of amplitude, or PGA. To confirm, Haz38 was run for Sites 2, 3, and 5 using both relations (Figs. 3.92, 3.93, and 3.95, respectively).

<u>Case 10</u>

Purpose: Area source with fixed depth of 5 km

Calculate the hazard at four sites for the area source defined in Figure 3.1. Use the truncated exponential model with M_{max} = 6.5 and M_{min}=5.0. Source should be uniformly distributed point sources (or approximations to point source) across the area (1 km grid spacing) at a fixed depth of 5 km. The attenuation relationship is Sadigh *et al*. (1997), rock, sigma = 0.

Results

Test Case 10 tests the computation of hazard from an area source. The case was defined as having uniformly distributed point sources throughout the area at a fixed depth. However, some of the codes tested do not implement point sources. These codes used an area source defined with uniformly distributed small faults that were set to be 1 square km in size. Even with these differences, results from all codes are consistent, as shown in Figures 3.98–3.101.

Case 11

Purpose: Volume source with fixed depth of 5–10 km

Calculate the hazard at four sites for area source defined in Figure 3.1. Use the truncated exponential model with M_{max} = 6.5 and M_{min}=5.0. The source should be uniformly distributed point sources (or approximation to point sources) throughout the volume (1 km grid spacing) defined by the area and a depth range of 5–10 km. The attenuation relationship is Sadigh *et al*. (1997), rock, sigma = 0.

Results

Test Case 11 extends the area source to a volume with point sources distributed over a depth range. The hazard results are shown in Figures 3.102–3.105. As with Test Case 10, the results from all codes are consistent with each other.

3.2 TEST CASE SET 2

The following describes the second set of test cases. Mean hazard results (probability of exceedance) for PGA defined at 0.001, 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.25, and 1.5 g were calculated. A Poisson model was assumed when converting rates to probabilities.

The second set of test cases is designed to test more complicated source geometry, multiple sources, and the implementation of logic trees. The participants provided the hazard results. However, due to schedule constraints, the results were not revised after all code issues related to Test Case 1 were resolved. The consensus results are not provided for Test Case 2.

For All Cases:

Use M_{min} = 5.0 with an integration step size small enough to adequately model the

Magnitude density function

Fault rupture dimension relationships:

Log (A) = M-4 σ_A=0

Log (W) = 0.5*M-2.15 σ_W=0

Log (L) = 0.5*M-1.85 σ_L=0

Aspect Ratio = 2

Case 1a–f (Non-Planar Fault)

Calculate the hazard at the three sites shown in Figure 3.106 due to the rupture of Fault A (unsegmented rupture only) using the truncated exponential model (M_{max} = 7.0), slip rate = 2 mm/yr, b-value = 0.9, and the Sadigh *et al*. (1997) attenuation relationship, rock, sigma = 0. Use the RA, RW, and RL relationships given below (with σ_{RA} = σ_{RL} = σ_{RW} = 0) to define the dimensions of the rupture planes. For cases 1a, 1b, and 1c use a dip of 60 degrees to the east. For cases 1d, 1e, and 1f use a dip of 60 degrees to the west.

The initial results for Site 1 are provided in Figure 3.107. This test case is designed to test how the geometry of non-straight-line faults are handled across available codes. Most codes to date model faults with planes. For a fault that bends along strike and dips other than 90 degrees, this creates gaps or overlaps of the planes at the bend along strike. Modeling approaches to address these gaps or overlaps range from ignoring the gap and combining planes at the intersection, to using the average strike to project the fault bottom points and connect (which changes the dip), to using conical surfaces to fill the gaps. This issue becomes more important when hanging wall factors are considered. Determination of whether a site is on the hanging wall or not may be sensitive to gaps. In addition, the Rx parameter in the Next Generation of Attenuation (NGA) ground motion relations can be sensitive to the correct geometric modeling of the fault.

Cases 2a–c (Multiple Sources, Deaggregation)

Calculate the hazard at the three sites shown in Figure 3.108 due to the area source, Fault B, and Fault C. For the area source, use the truncated exponential model (M_{max}=6.5) and the cumulative number of events with **M** ≥ 5.0 = 0.0395. For Fault B (L=75 km), use the characteristic model

(Youngs and Coppersmith [1985], M_{char} = 7.0, M_{max} = 7.25), and slip rate = 2 mm/yr. For Fault C (L=25 km), use the characteristic model (Youngs and Coppersmith [1985], M_{char} = 6.5, M_{max} = 6.75), and slip rate = 1 mm/yr. For all sources, use the Sadigh *et al*. (1997) attenuation relationship, rock, sigma truncated at 3 standard deviations, b-value = 0.9, a M_{min} = 5.0. For the faults, use the RA, RW, and RL relationships given below (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Provide the following deaggregation results for peak ground acceleration at Sites 1 and 3 corresponding to the annual exceedance probabilities of 0.01 and 0.0001:

Modal values M*, D*, ε*

Mean values M-bar, D-bar, ε-bar

Test Case 2 was designed to look at multiple sources and deaggregation. An example of early hazard results is shown in Figure 3.109. With perhaps two outliers, the results are fairly closely grouped.

Cases 3a–c (Recurrence Interval, Characteristic Model)

Calculate the hazard for all three sites due to the rupture of Fault D (Fig. 3.110) using the characteristic model (Youngs and Coppersmith [1985], M_{char} = 6.2, M_{max} = 6.45), recurrence interval = 1000 years, and the Sadigh *et al*. (1997) attenuation relationship, rock, sigma = 0. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Test Case 3 is an extension of Test Case 7 from Set 1. It is intended to test the use of the recurrence interval using the characteristic model of earthquake magnitude distribution. Early results are shown in Figure 3.111 for Site 1.

Cases 4a–c (Recurrence Interval, Truncated Normal Model)

Calculate the hazard for all three sites due to the rupture of Fault D (Fig. 3.110) using the truncated normal model (M_{char} = 6.2, M_{max} = 6.5, sigma = 0.25), recurrence interval = 1000 years, and the Sadigh *et al*. (1997) attenuation relationship, rock, sigma = 0. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Test Case 4 is intended to test the use of the recurrence interval with the truncated normal distribution of earthquake magnitude. Early results are shown in Figure 3.112 for Site 1.

Cases 5a–c (Logic Tree, Fractiles)

Calculate the hazard for all three sites due to the rupture of Fault A (Fig. 3.106) as shown in the logic tree in Figure 3.113. Provide the mean hazard along with the 5^{th} and 95^{th} percentile fractiles. Use the Sadigh *et al*. (1997) attenuation relationship, rock, truncate sigma at three standard deviations. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define dimensions of rupture planes.

The initial results for Test Case 5 for Site 1 is shown in Figure 3.114. Due to a lack of discussion and revision, it is unknown if the wide range of results is a result of different interpretation of the logic tree or input errors.

Cases 6a–c (Listric Fault)

Calculate the hazard for all three sites due to the rupture of Fault E (Fig. 3.115) using the truncated exponential model (M_{max} = 6.5) and the Sadigh *et al*. (1997) attenuation relationship, rock, sigma = 0. Assume that the fault is strike-slip for the attenuation relationship. Slip-rate = 2 mm/yr. Use the RA, RW, and RL relationships (with $\sigma_{RA} = \sigma_{RL} = \sigma_{RW} = 0$) to define the dimensions of the rupture planes.

Test Case 6 is intended to examine the various modeling approaches for a listric fault and its effect on hazard. The initial results are shown in Figure 3.116. Differences in rate could be a result of different fault areas due to the different fault geometries, but also could be due to the integration issues discovered in Test Case 1.

Cases 7a–c (Intraslab Zone)

Calculate the hazard for all three sites due to rupture of the intraslab zone with uniform thickness of 10 km (Fig. 3.117) using the truncated exponential model (M_{max} = 7.5) and the Youngs *et al.* (1997) attenuation relationship, with sigma truncated at three standard deviations. The *b*-value is 0.9. The rate for events greater and equal to 5 is 0.005644.

Test Case 7 is intended to test the modeling of an intraslab zone. The slab was defined as a dipping volume. The modeling approaches for this varied among codes. Most used a series of horizontal volumes that stairstep down from the shallow end to the deeper end of the slab. Figure 3.118 shows the initial results for Site 1.

4 Conclusions

This report describes a project to test and verify the numerical approaches and software used in PSHA. A Working Group was organized and each member tested their own computer code in two sets of tests. Through several iterations, codes were tested and acceptable answers were established either through analytical solutions or as the consensus answer from the test case results. Given the significant experience of the Working Group members, it was somewhat surprising to find major differences in the initial code verification results. However, more often than not, the differences were due to the differences in the numerical approaches used to solve a particular mathematical problem. Once an agreed-upon solution was adopted and the source characterization clearly defined, the results generally converged.

The verification tests are available to any PSHA code developer/user worldwide through this publication and the PEER website. The test cases will be used as a standard verification for all PSHA codes to be used in projects for the PEER Lifelines Program sponsors, which include the California Department of Transportation (Caltrans), the Pacific Gas & Electric Company (PG&E), and the California Energy Commission (CEC).

REFERENCES

Abrahamson, N., 2000, Effects of rupture directivity on probabilistic seismic hazard analysis: Sixth International Conference on Seismic Zonation, v. I, p. 151-156.

Abrahamson, N.A. and Silva, W.J., 1997, Empirical response spectral attenuation relations for shallow crustal earthquakes: Seismological Research Letters, v. 68, p. 94-127.

Campbell, K.C., 1997, Empirical near source attenuation relationships for horizontal and vertical components of peak ground acceleration, velocity, and pseudo-absolute acceleration response spectra: Seism. Res. Lett. 68, 154-179.

Cornell, C. A., 1968, Engineering seismic risk analysis: Bulletin of the Seismological Society of America, v. 58, p. 1583-1606.

Frankel, A., Mueller, C., Barnard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, National seismic hazard maps; documentation June 1996: U.S. Geological Survey Open-File Report 96-532, 110 p.

McGuire, R.K., 2004, Seismic hazard and risk analysis: Earthquake Engineering Research Institute, Monograph 10, 221 p.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008-1128, 61 p.

Sadigh, K., C.-Y. Chang, J.A. Egan, F. Makdisi, and R.R. Youngs 1997. Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, 68, 180-189.

Senior Seismic Hazard Analysis Committee (SSHAC), 1997, Recommendations for probabilistic seismic hazard analysis: Guidance on uncertainty and use of experts: U.S. Nuclear Regulatory Commission (NRC) NUREG/CR-6372, Washington, D.C.

Stepp, J.C., Wong, I., Whitney, J., Quittmeyer, R., Abrahamson, N., Coppersmith, K., Toro, G., Youngs, R., Savy, J., Sullivan, T., and Yucca Mountain PSHA Project Members, 2001, Probabilistic seismic hazard analyses for ground motions and fault displacement at Yucca Mountain, Nevada: Earthquake Spectra, v. 17, p.113-151.

Wong, I.G., Thomas, P.A., and Abrahamson, N., 2004, The PEER-Lifelines validation of software used in probabilistic seismic hazard analysis, *in* 2004 Geotechnical Engineering for Transportation Projects, Proceedings, M. Yegian and E. Kavazanjian (eds.), American Society of Civil Engineers, Geotechnical Special Publication No. 126, v. 1, p. 807-815.

Youngs, R.R. and Coppersmith, K.J., 1985, Implications of fault slip rates and earthquake recurrence models to probabilistic seismic hazard estimates: Bulletin of the Seismological Society of America, v. 75, p. 939-964.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P. and Green, R.K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch front, Utah, in P. L. Gori and W.W. Hays (eds.), Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah, U. S. Geological Survey Open-File Report 87-585, v. II, p. M1-M110.

Appendix A

SITE AND SOURCE COORDINATES

Sites for Test Set 1, Cases 1 through 9

Site	Latitude	Longitude	Comment
1	38.113	-122.000	On Fault Midpoint along Strike
2	38.113	-122.114	10km West of fault, at midpoint
3	38.111	-122.570	50km West of fault, at midpoint
4	38.000	-122.000	South end of fault
5	37.910	-122.000	10km south of fault along strike
6	38.225	-122.000	North end of fault
7	38.113	-121.886	10km East of fault, at midpoint

Coordinates for 25 km fault for Test Set 1, Cases 1 through 9

Latitude	Longitude	Comment
38.00000	-122.000	South end of fault
38.22480	-122.000	North end of fault

Sites for Test Set 1, Cases 10 and 11

Site	Latitude	Longitude	Comment
1	38.000	-122.000	Center of Area 1
2	37.550	-122.000	50km N of Site 1
3	37.099	-122.000	On Area Boundary
4	36.874	-122.000	25km N of Area Boundary

Coordinates for Area Source for Test Set 1, Cases 10 and 11

Latitude	Longitude
38.901	-122.000
38.899	-121.920
38.892	-121.840
38.881	-121.760
38.866	-121.682
38.846	-121.606
38.822	-121.532
38.794	-121.460
38.762	-121.390
38.727	-121.324
38.688	-121.261
38.645	-121.202
38.600	-121.147
38.551	-121.096
38.500	-121.050
38.446	-121.008
38.390	-120.971
38.333	-120.940
38.273	-120.913
38.213	-120.892
38.151	-120.876
38.089	-120.866
38.026	-120.862
37.963	-120.863
37.900	-120.869
37.838	-120.881
37.777	-120.899
37.717	-120.921
37.658	-120.949

Latitude	Longitude
37.601	-120.982
37.545	-121.020
37.492	-121.063
37.442	-121.110
37.394	-121.161
37.349	-121.216
37.308	-121.275
37.269	-121.337
37.234	-121.403
37.203	-121.471
37.176	-121.542
37.153	-121.615
37.133	-121.690
37.118	-121.766
37.108	-121.843
37.101	-121.922
37.099	-122.000
37.101	-122.078
37.108	-122.157
37.118	-122.234
37.133	-122.310
37.153	-122.385
37.176	-122.458
37.203	-122.529
37.234	-122.597
37.269	-122.663
37.308	-122.725
37.349	-122.784
37.394	-122.839
37.442	-122.890
37.492	-122.937
37.545	-122.980
37.601	-123.018
37.658	-123.051
37.717	-123.079
37.777	-123.101
37.838	-123.119
37.900	-123.131
37.963	-123.137
38.026	-123.138
38.089	-123.134
38.151	-123.124
38.213	-123.108
38.273	-123.087
38.333	-123.060
38.390	-123.029
38.446	-122.992
38.500	-122.950
38.551	-122.904
38.600	-122.853
38.645	-122.798
38.688	-122.739
38.727	-122.676
38.762	-122.610

Latitude	Longitude
38.794	-122.540
38.822	-122.468
38.846	-122.394
38.866	-122.318
38.881	-122.240
38.892	-122.160
38.899	-122.080

Sites for Test Set 2

Test Case	Site	Latitude	Longitude
1	**1**	38.1126	-121.886
1	**2**	38.1800	-121.886
1	**3**	38.2696	-122.114
2	**1**	37.5495	-122.000
2	**2**	37.0990	-122.000
2	**3**	36.8737	-122.000
3–7	**1**	38.1126	-121.886
3–7	**2**	38.2252	-122.000
3–7	**3**	38.0000	-122.000

Fault Coordinates for Test Set 2

Test Case	Fault	Latitude	Longitude
1, 5	**Fault A - Unsegmented**	38.6147	-121.7130
1, 5	**Fault A - Unsegmented**	38.4200	-121.8569
1, 5	**Fault A - Unsegmented**	38.2248	-122.0000
1, 5	**Fault A - Unsegmented**	38.0000	-122.0000
1, 5	**Fault A - Unsegmented**	37.8049	-121.8581
1, 5	**Fault A - Unsegmented**	37.6095	-121.7169
1, 5	**Fault A - Segment A**	38.6147	-121.7130
1, 5	**Fault A - Segment A**	38.4200	-121.8569
1, 5	**Fault A - Segment B**	38.4200	-121.8569
1, 5	**Fault A - Segment B**	38.2248	-122.0000
1, 5	**Fault A - Segment C**	38.2248	-122.0000
1, 5	**Fault A - Segment C**	38.0000	-122.0000
1, 5	**Fault A - Segment D**	38.0000	-122.0000
1, 5	**Fault A - Segment D**	37.8049	-121.8581
1, 5	**Fault A - Segment E**	37.8049	-121.8581
1, 5	**Fault A - Segment E**	37.6095	-121.7169
2	Fault B	38.6749	-121.5691
2	Fault B	38.6749	-122.4309
2	Fault C	37.3242	-121.8590
2	Fault C	37.3242	-122.1410
3, 4	Fault D	38.2248	-122.0000
3, 4	Fault D	38.0000	-122.0000
6	Fault E	38.2248	-122.0000
6	Fault E	38.0000	-122.0000
7	Intraslab	38.4496	-122.0000
7	Intraslab	37.7752	-122.0000

Area Source Coordinates for Test Set 2, Case 2

Latitude	Longitude
38.901	-122.000
38.899	-121.920
38.892	-121.840
38.881	-121.760
38.866	-121.682
38.846	-121.606
38.822	-121.532
38.794	-121.460
38.762	-121.390
38.727	-121.324
38.688	-121.261
38.645	-121.202
38.600	-121.147
38.551	-121.096
38.500	-121.050
38.446	-121.008
38.390	-120.971
38.333	-120.940
38.273	-120.913
38.213	-120.892
38.151	-120.876
38.089	-120.866
38.026	-120.862
37.963	-120.863
37.900	-120.869
37.838	-120.881
37.777	-120.899
37.717	-120.921
37.658	-120.949
37.601	-120.982
37.545	-121.020
37.492	-121.063
37.442	-121.110
37.394	-121.161
37.349	-121.216
37.308	-121.275
37.269	-121.337
37.234	-121.403
37.203	-121.471
37.176	-121.542
37.153	-121.615
37.133	-121.690
37.118	-121.766
37.108	-121.843
37.101	-121.922
37.099	-122.000
37.101	-122.078
37.108	-122.157
37.118	-122.234
37.133	-122.310
37.153	-122.385
37.176	-122.458
37.203	-122.529

Latitude	Longitude
37.234	-122.597
37.269	-122.663
37.308	-122.725
37.349	-122.784
37.394	-122.839
37.442	-122.890
37.492	-122.937
37.545	-122.980
37.601	-123.018
37.658	-123.051
37.717	-123.079
37.777	-123.101
37.838	-123.119
37.900	-123.131
37.963	-123.137
38.026	-123.138
38.089	-123.134
38.151	-123.124
38.213	-123.108
38.273	-123.087
38.333	-123.060
38.390	-123.029
38.446	-122.992
38.500	-122.950
38.551	-122.904
38.600	-122.853
38.645	-122.798
38.688	-122.739
38.727	-122.676
38.762	-122.610
38.794	-122.540
38.822	-122.468
38.846	-122.394
38.866	-122.318
38.881	-122.240
38.892	-122.160

SOLUTIONS TO SET 1, TEST CASES 2, 4, 5, 6, 7 AND 9b

Hand Solutions for Set 1, Test Case 2

Peak Ground Acceleration (g)	Annual Exceedance Probability						
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**
0.001	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.01	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.05	1.59E-02	1.59E-02	0.00E+00	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.1	1.59E-02	1.59E-02	0.00E+00	1.59E-02	1.56E-02	1.59E-02	1.59E-02
0.15	1.59E-02	1.59E-02	0.00E+00	1.59E-02	7.69E-03	1.59E-02	1.59E-02
0.2	1.59E-02	1.59E-02	0.00E+00	1.58E-02	1.60E-03	1.58E-02	1.59E-02
0.25	1.59E-02	0.00E+00	0.00E+00	1.20E-02	0.00E+00	1.20E-02	0.00E+00
0.3	1.59E-02	0.00E+00	0.00E+00	8.64E-03	0.00E+00	8.64E-03	0.00E+00
0.35063	1.59E-02	0.00E+00	0.00E+00	5.68E-03	0.00E+00	5.68E-03	0.00E+00
0.4	1.18E-02	0.00E+00	0.00E+00	3.09E-03	0.00E+00	3.09E-03	0.00E+00
0.45	8.23E-03	0.00E+00	0.00E+00	1.51E-03	0.00E+00	1.51E-03	0.00E+00
0.5	5.23E-03	0.00E+00	0.00E+00	6.08E-04	0.00E+00	6.08E-04	0.00E+00
0.55	2.64E-03	0.00E+00	0.00E+00	1.54E-04	0.00E+00	1.54E-04	0.00E+00
0.6	3.63E-04	0.00E+00	0.00E+00	2.92E-06	0.00E+00	2.92E-06	0.00E+00
0.65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Hand Solutions for Set 1, Test Case 4

Peak Ground Acceleration (g)	Site 1	Site 2	Site 7
0.001	1.68E-02	1.68E-02	1.68E-02
0.01	1.68E-02	1.68E-02	1.68E-02
0.05	1.68E-02	1.68E-02	1.68E-02
0.10	1.68E-02	1.68E-02	1.68E-02
0.15	1.68E-02	1.68E-02	1.68E-02
0.20	1.68E-02	1.68E-02	1.64E-02
0.25	1.68E-02	1.68E-02	4.17E-03
0.30	1.68E-02	0.00E+00	0.00E+00
0.35	1.68E-02	0.00E+00	0.00E+00
0.40	1.37E-02	0.00E+00	0.00E+00
0.45	1.01E-02	0.00E+00	0.00E+00
0.50	7.03E-03	0.00E+00	0.00E+00
0.55	4.37E-03	0.00E+00	0.00E+00
0.60	2.00E-03	0.00E+00	0.00E+00
0.65	0.00E+00	0.00E+00	0.00E+00

Hand Solutions for Set 1, Test Case 5

Peak Ground Acceleration (g)	Site 4	Site 5	Site 6
0.001	3.99E-02	3.99E-02	3.99E-02
0.01	3.99E-02	3.99E-02	3.99E-02
0.05	3.98E-02	3.14E-02	3.98E-02
0.1	2.99E-02	1.21E-02	2.99E-02
0.15	2.00E-02	4.41E-03	2.00E-02
0.2	1.30E-02	1.89E-03	1.30E-02
0.25	8.58E-03	7.53E-04	8.58E-03
0.3	5.72E-03	1.25E-04	5.72E-03
0.35	3.88E-03	0.00E+00	3.88E-03
0.4	2.69E-03	0.00E+00	2.69E-03
0.45	1.91E-03	0.00E+00	1.91E-03
0.5	1.37E-03	0.00E+00	1.37E-03
0.55	9.74E-04	0.00E+00	9.74E-04
0.6	6.75E-04	0.00E+00	6.75E-04
0.7	2.52E-04	0.00E+00	2.52E-04
0.8	0.00E+00	0.00E+00	0.00E+00

Hand Solutions for Set 1, Test Case 6

Peak Ground Acceleration (g)	Site 4	Site 5	Site 6
0.001	7.75E-03	7.75E-03	7.75E-03
0.01	7.75E-03	7.75E-03	7.75E-03
0.05	7.75E-03	7.75E-03	7.75E-03
0.075	7.75E-03	7.75E-03	7.75E-03
0.10	7.74E-03	7.37E-03	7.74E-03
0.15	7.64E-03	5.81E-03	7.64E-03
0.20	7.31E-03	3.57E-03	7.31E-03
0.25	6.73E-03	1.52E-03	6.73E-03
0.30	5.99E-03	2.26E-04	5.99E-03
0.40	4.27E-03	0.00E+00	4.27E-03
0.50	2.64E-03	0.00E+00	2.64E-03
0.60	1.35E-03	0.00E+00	1.35E-03
0.65	8.63E-04	0.00E+00	8.63E-04
0.70	4.74E-04	0.00E+00	4.74E-04
0.80	0.00E+00	0.00E+00	0.00E+00

Hand Solutions for Set 1, Test Case 7

Peak Ground Acceleration (g)	Site 4	Site 5	Site 6
0.001	1.14E-02	1.14E-02	1.14E-02
0.01	1.14E-02	1.14E-02	1.14E-02
0.05	1.14E-02	1.03E-02	1.14E-02
0.1	1.01E-02	7.65E-03	1.01E-02
0.15	8.72E-03	5.66E-03	8.72E-03
0.2	7.75E-03	3.50E-03	7.75E-03
0.25	6.84E-03	1.40E-03	6.84E-03
0.3	5.95E-03	4.89E-06	5.95E-03
0.35	5.06E-03	0.00E+00	5.06E-03
0.4	4.18E-03	0.00E+00	4.18E-03
0.45	3.34E-03	0.00E+00	3.34E-03
0.5	2.56E-03	0.00E+00	2.56E-03
0.55	1.85E-03	0.00E+00	1.85E-03
0.6	1.20E-03	0.00E+00	1.20E-03
0.7	1.87E-04	0.00E+00	1.87E-04
0.80	0.00E+00	0.00E+00	0.00E+00

Hand Solutions for Set 1, Test Case 9b

Peak Ground Acceleration (g)	Site 1	Site 2	Site 7
0.001	1.68E-02	1.68E-02	1.68E-02
0.01	1.68E-02	1.68E-02	1.68E-02
0.05	1.68E-02	1.68E-02	1.68E-02
0.1	1.68E-02	1.68E-02	1.68E-02
0.15	1.68E-02	1.68E-02	1.68E-02
0.2	1.68E-02	1.68E-02	1.68E-02
0.25	1.68E-02	1.68E-02	1.68E-02
0.3	1.68E-02	1.68E-02	8.76E-03
0.35	1.68E-02	1.68E-02	8.46E-04
0.4	1.68E-02	1.68E-02	0.00E+00
0.45	1.68E-02	1.68E-02	0.00E+00
0.5	1.68E-02	0.00E+00	0.00E+00
0.55	1.46E-02	0.00E+00	0.00E+00
0.6	1.22E-02	0.00E+00	0.00E+00
0.7	7.66E-03	0.00E+00	0.00E+00
0.8	2.70E-03	0.00E+00	0.00E+00

MEAN RESULTS FOR TEST CASES WITHOUT HAND SOLUTIONS

Mean Results Set 1, Case 4

Peak Ground Acceleration (g)	Site 3	Site 4	Site 5	Site 6
0.001	1.68E-02	1.68E-02	1.68E-02	1.68E-02
0.01	1.68E-02	1.68E-02	1.68E-02	1.68E-02
0.05		1.68E-02	1.68E-02	1.68E-02
0.1		1.68E-02	1.68E-02	1.68E-02
0.15		1.68E-02	1.23E-02	1.68E-02
0.2		1.68E-02	5.22E-03	1.68E-02
0.25		1.57E-02	4.75E-04	1.57E-02
0.3		1.18E-02		1.18E-02
0.35		8.42E-03		8.40E-03
0.4		5.11E-03		5.09E-03
0.45		2.88E-03		2.86E-03
0.5		1.50E-03		
0.55		6.44E-04		
0.6		1.75E-04		

Mean Results Set 1, Case 5

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 7
0.001	4.00E-02	4.00E-02	4.00E-02	4.00E-02
0.01	4.00E-02	4.00E-02	4.00E-02	4.00E-02
0.05	4.00E-02	4.00E-02		4.00E-02
0.1	3.99E-02	3.31E-02		3.31E-02
0.15	3.46E-02	1.22E-02		1.22E-02
0.2	2.57E-02	4.85E-03		4.85E-03
0.25	1.89E-02	1.76E-03		1.76E-03
0.3	1.37E-02	2.40E-04		2.40E-04
0.35	9.88E-03			
0.4	6.93E-03			
0.45	4.84E-03			
0.5	3.36E-03			
0.55	2.34E-03			
0.6	1.52E-03			
0.7	5.12E-04			

Mean Results Set 1, Case 6

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 7
0.001	7.74E-03	7.74E-03	7.74E-03	7.74E-03
0.01	7.74E-03	7.74E-03	7.74E-03	7.74E-03
0.05	7.74E-03	7.74E-03		7.74E-03
0.1	7.74E-03	7.74E-03		7.74E-03
0.15	7.74E-03	7.70E-03		7.70E-03
0.2	7.73E-03	6.77E-03		6.77E-03
0.25	7.69E-03	3.60E-03		3.60E-03
0.3	7.55E-03	4.50E-04		4.50E-04
0.35	7.21E-03			
0.4	6.65E-03			
0.45	5.89E-03			
0.5	4.98E-03			

Mean Results Set 1, Case 7

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 7
0.001	1.16E-02	1.16E-02	1.16E-02	1.16E-02
0.01	1.16E-02	1.16E-02	1.16E-02	1.16E-02
0.05	1.16E-02	1.16E-02		1.16E-02
0.1	1.16E-02	1.06E-02		1.06E-02
0.15	1.09E-02	7.79E-03		7.79E-03
0.2	9.67E-03	6.76E-03		6.76E-03
0.25	8.66E-03	3.62E-03		3.62E-03
0.3	7.96E-03			
0.35	7.39E-03			
0.4	6.71E-03			
0.45	5.87E-03			
0.5	4.95E-03			
0.55	4.00E-03			
0.6	2.91E-03			
0.7	8.50E-04			

Mean Results Set 1, Case 8a

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
0.001	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.01	1.59E-02	1.59E-02	1.57E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.05	1.59E-02	1.59E-02	3.42E-03	1.59E-02	1.55E-02	1.59E-02	1.59E-02
0.1	1.59E-02	1.47E-02	3.19E-04	1.55E-02	1.20E-02	1.55E-02	1.47E-02
0.15	1.56E-02	1.20E-02	4.15E-05	1.41E-02	7.98E-03	1.40E-02	1.20E-02
0.2	1.48E-02	8.98E-03	7.37E-06	1.22E-02	4.99E-03	1.22E-02	8.98E-03
0.25	1.36E-02	6.41E-03	1.61E-06	1.03E-02	3.08E-03	1.02E-02	6.41E-03
0.3	1.22E-02	4.49E-03	4.03E-07	8.39E-03	1.91E-03	8.38E-03	4.49E-03
0.35	1.09E-02	3.09E-03		6.80E-03	1.21E-03	6.79E-03	3.09E-03
0.4	9.50E-03	2.14E-03		5.49E-03	7.68E-04	5.48E-03	2.14E-03
0.45	8.12E-03	1.49E-03		4.37E-03	4.99E-04	4.36E-03	1.49E-03
0.5	6.99E-03	1.04E-03		3.52E-03	3.25E-04	3.51E-03	1.04E-03
0.55	5.99E-03	7.40E-04		2.84E-03	2.19E-04	2.83E-03	7.40E-04
0.6	5.12E-03	5.24E-04		2.29E-03	1.48E-04	2.28E-03	5.24E-04
0.7	3.68E-03	2.68E-04		1.51E-03	7.01E-05	1.50E-03	2.68E-04
0.8	2.65E-03	1.44E-04		1.00E-03	3.50E-05	9.97E-04	1.44E-04
0.9	1.91E-03	7.89E-05		6.74E-04	1.81E-05	6.71E-04	7.89E-05
1	1.40E-03	4.48E-05		4.58E-04	9.72E-06	4.56E-04	4.48E-05

Mean Results Set 1, Case 8b

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
0.001	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.01	1.59E-02	1.59E-02	1.57E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.05	1.59E-02	1.59E-02	3.14E-03	1.59E-02	1.56E-02	1.59E-02	1.59E-02
0.1	1.59E-02	1.47E-02		1.55E-02	1.20E-02	1.55E-02	1.47E-02
0.15	1.56E-02	1.19E-02		1.41E-02	7.85E-03	1.41E-02	1.19E-02
0.2	1.48E-02	8.87E-03		1.22E-02	4.78E-03	1.22E-02	8.87E-03
0.25	1.36E-02	6.17E-03		1.02E-02	2.80E-03	1.02E-02	6.17E-03
0.3	1.22E-02	4.23E-03		8.28E-03	1.59E-03	8.27E-03	4.23E-03
0.35	1.07E-02	2.81E-03		6.58E-03	8.67E-04	6.57E-03	2.81E-03
0.4	9.30E-03	1.83E-03		5.25E-03	4.55E-04	5.23E-03	1.83E-03
0.45	8.00E-03	1.15E-03		4.16E-03	2.28E-04	4.11E-03	1.15E-03
0.5	6.83E-03			3.25E-03		3.24E-03	
0.55	5.74E-03			2.53E-03		2.52E-03	
0.6	4.85E-03			1.98E-03		1.97E-03	
0.7	3.40E-03			1.18E-03		1.17E-03	
0.8	2.33E-03			7.03E-04		6.92E-04	
0.9	1.57E-03			4.08E-04		4.02E-04	
1	1.04E-03			2.28E-04		2.27E-04	

Mean Results Set 1, Case 8c

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
0.001	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.01	1.59E-02	1.59E-02	1.57E-02	1.59E-02	1.59E-02	1.59E-02	1.59E-02
0.05	1.59E-02	1.59E-02	3.40E-03	1.59E-02	1.55E-02	1.59E-02	1.59E-02
0.1	1.59E-02	1.47E-02	2.97E-04	1.55E-02	1.20E-02	1.55E-02	1.47E-02
0.15	1.56E-02	1.20E-02	1.99E-05	1.41E-02	7.97E-03	1.41E-02	1.20E-02
0.2	1.48E-02	8.97E-03		1.22E-02	4.96E-03	1.22E-02	8.97E-03
0.25	1.36E-02	6.40E-03		1.03E-02	3.05E-03	1.02E-02	6.40E-03
0.3	1.22E-02	4.47E-03		8.40E-03	1.88E-03	8.38E-03	4.47E-03
0.35	1.09E-02	3.08E-03		6.80E-03	1.17E-03	6.79E-03	3.08E-03
0.4	9.49E-03	2.12E-03		5.48E-03	7.42E-04	5.47E-03	2.12E-03
0.45	8.12E-03	1.47E-03		4.36E-03	4.70E-04	4.35E-03	1.47E-03
0.5	6.97E-03	1.02E-03		3.51E-03	2.99E-04	3.50E-03	1.02E-03
0.55	5.97E-03	7.14E-04		2.82E-03	1.93E-04	2.81E-03	7.14E-04
0.6	5.04E-03	5.01E-04		2.27E-03	1.24E-04	2.27E-03	5.01E-04
0.7	3.65E-03	2.48E-04		1.49E-03	5.08E-05	1.48E-03	2.48E-04
0.8	2.62E-03	1.23E-04		9.79E-04	1.98E-05	9.66E-04	1.23E-04
0.9	1.88E-03			6.52E-04		6.42E-04	
1	1.36E-03			4.37E-04		4.35E-04	

Mean Results Set 1, Case 9a

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
0.001	1.69E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02
0.01	1.69E-02	1.69E-02	1.68E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02
0.05	1.69E-02	1.68E-02	6.90E-03	1.68E-02	1.66E-02	1.68E-02	1.68E-02
0.1	1.68E-02	1.65E-02	1.14E-03	1.66E-02	1.40E-02	1.66E-02	1.58E-02
0.15	1.65E-02	1.48E-02	1.99E-04	1.56E-02	1.03E-02	1.56E-02	1.31E-02
0.2	1.58E-02	1.26E-02	2.79E-05	1.39E-02	6.99E-03	1.39E-02	1.02E-02
0.25	1.47E-02	1.02E-02		1.20E-02	4.64E-03	1.20E-02	7.50E-03
0.3	1.34E-02	7.89E-03		1.02E-02	3.07E-03	1.02E-02	5.40E-03
0.35	1.19E-02	6.02E-03		8.45E-03	2.04E-03	8.43E-03	3.85E-03
0.4	1.05E-02	4.61E-03		6.95E-03	1.36E-03	6.94E-03	2.73E-03
0.45	9.15E-03	3.50E-03		5.70E-03	9.21E-04	5.69E-03	1.94E-03
0.5	7.94E-03	2.64E-03		4.66E-03	6.22E-04	4.65E-03	1.39E-03
0.55	6.85E-03	1.98E-03		3.81E-03	4.22E-04	3.80E-03	9.92E-04
0.6	5.90E-03	1.53E-03		3.16E-03	2.91E-04	3.11E-03	7.20E-04
0.7	4.30E-03	8.78E-04		2.12E-03	1.37E-04	2.11E-03	3.74E-04
0.8	3.16E-03	5.00E-04		1.43E-03	6.41E-05	1.43E-03	1.96E-04
0.9	2.30E-03	2.97E-04		9.87E-04	2.91E-05	9.83E-04	1.01E-04
1	1.68E-03	1.73E-04		6.77E-04	1.23E-05	6.74E-04	4.99E-05

Mean Results Set 1, Case 9b

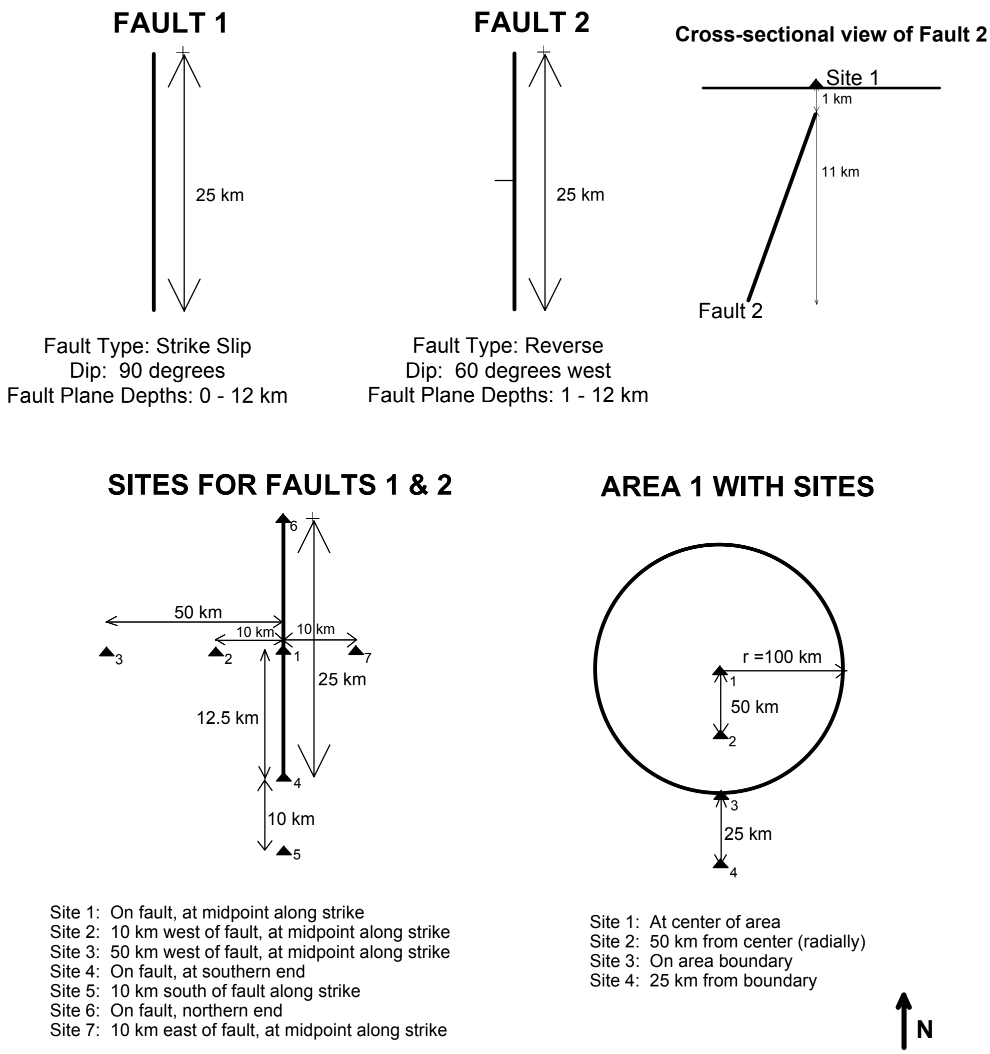
Peak Ground Acceleration (g)	Site 3	Site 4	Site 5	Site 6
0.001	1.69E-02	1.69E-02	1.69E-02	1.69E-02
0.01	1.69E-02	1.69E-02	1.69E-02	1.69E-02
0.05	1.69E-02	1.69E-02	1.69E-02	1.69E-02
0.1		1.69E-02	1.69E-02	1.69E-02
0.15		1.69E-02	1.69E-02	1.69E-02
0.2		1.69E-02	1.11E-02	1.69E-02
0.25		1.69E-02	5.74E-03	1.69E-02
0.3		1.67E-02	2.02E-03	1.67E-02
0.35		1.46E-02		1.45E-02
0.4		1.19E-02		1.19E-02
0.45		9.80E-03		9.77E-03
0.5		7.90E-03		7.87E-03
0.55		5.81E-03		5.72E-03
0.6		4.09E-03		4.06E-03
0.7		1.77E-03		1.72E-03
0.8		2.85E-04		2.80E-04
0.9				
1				

Mean Results Set 1, Case 10

Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4
0.001	3.87E-02	3.87E-02	3.87E-02	3.83E-02
0.01	2.19E-02	1.82E-02	9.32E-03	5.33E-03
0.05	2.97E-03	2.96E-03	1.39E-03	1.25E-04
0.1	9.22E-04	9.21E-04	4.41E-04	1.63E-06
0.15	3.59E-04	3.59E-04	1.76E-04	
0.2	1.31E-04	1.31E-04	6.47E-05	
0.25	4.76E-05	4.76E-05	2.27E-05	
0.3	1.72E-05	1.72E-05	8.45E-06	
0.35	5.38E-06	5.37E-06	2.66E-06	
0.4	1.18E-06	1.18E-06	5.84E-07	

Mean Results Set 1, Case 11

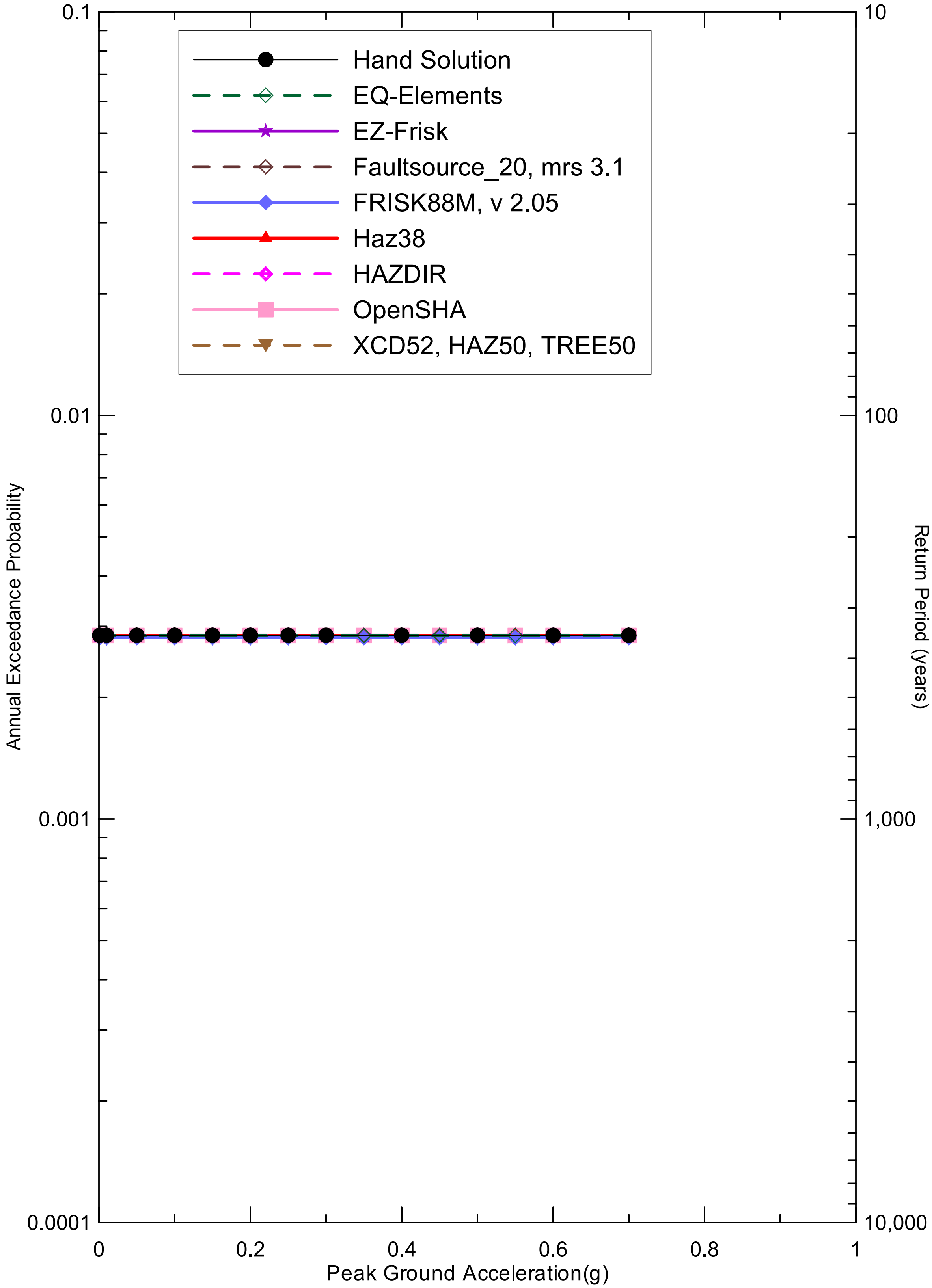
Peak Ground Acceleration (g)	Site 1	Site 2	Site 3	Site 4
0.001	3.87E-02	3.87E-02	3.87E-02	3.84E-02
0.01	2.18E-02	1.81E-02	9.27E-03	5.33E-03
0.05	2.83E-03	2.83E-03	1.32E-03	1.18E-04
0.1	7.91E-04	7.90E-04	3.79E-04	1.24E-06
0.15	2.43E-04	2.44E-04	1.18E-04	
0.2	7.33E-05	7.32E-05	3.60E-05	
0.25	2.23E-05	2.21E-05	1.08E-05	
0.3	6.42E-06	6.50E-06	2.95E-06	
0.35	1.31E-06	1.30E-06	6.18E-07	
0.4	1.72E-07	1.60E-07	7.92E-08	
0.45	3.05E-09	3.09E-09	1.34E-09	



PEER PSHA VERIFICATION

FAULT AND SITE GEOMETRY
FOR TEST CASE SET #1

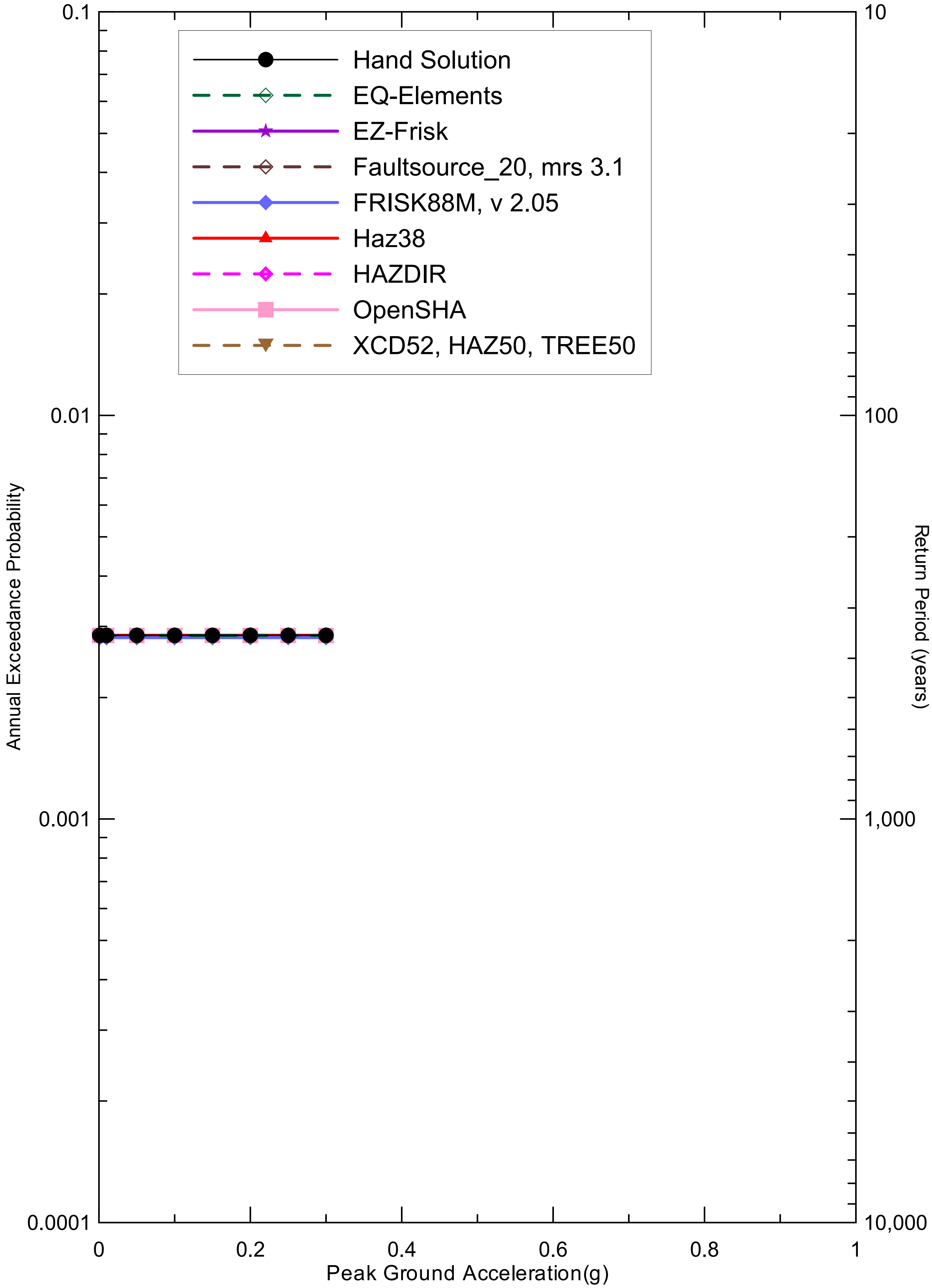
Figure 3.1



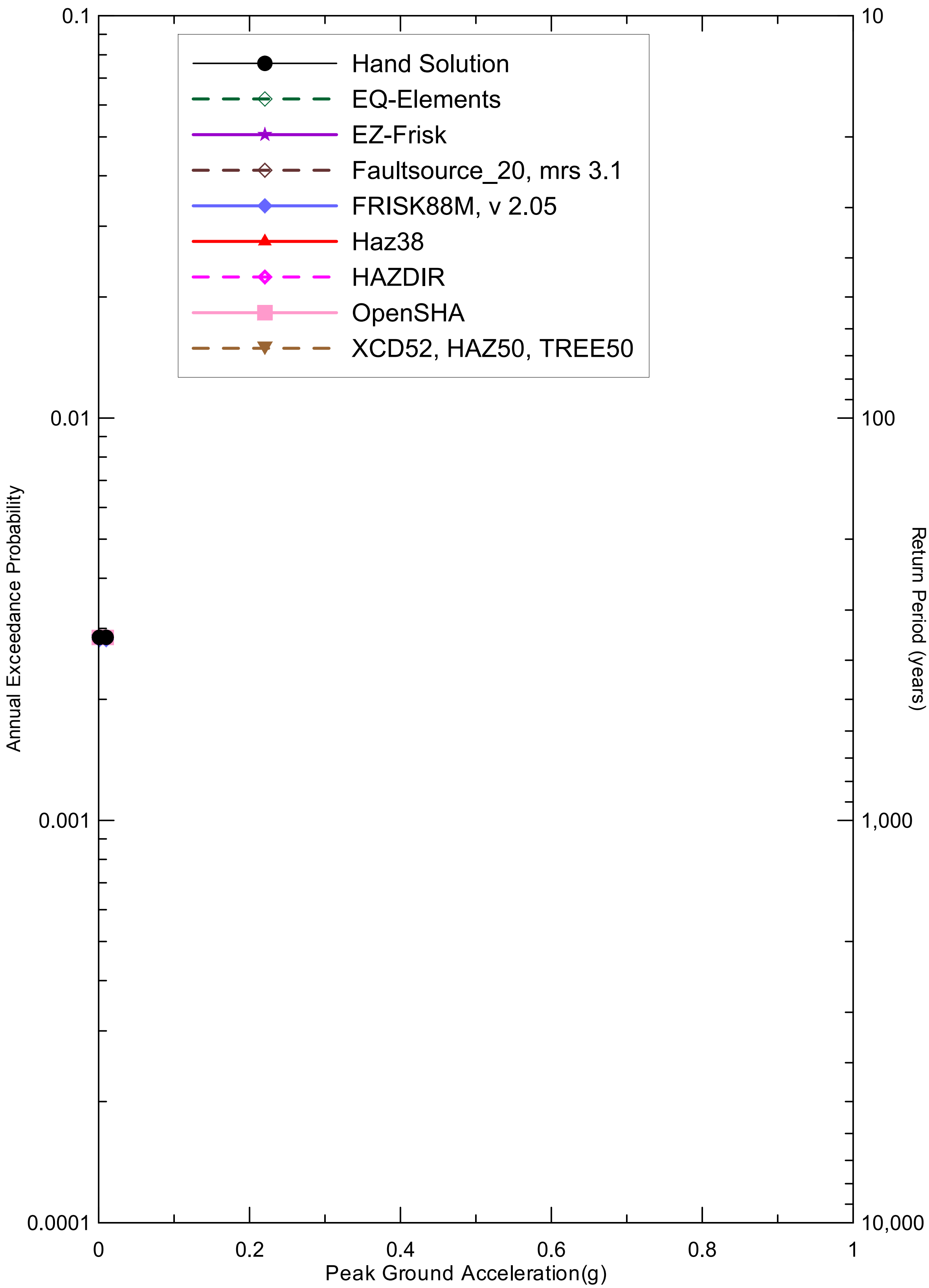
PEER PSHA VERIFICATION

TEST SET 1, CASE 1, SITE 1

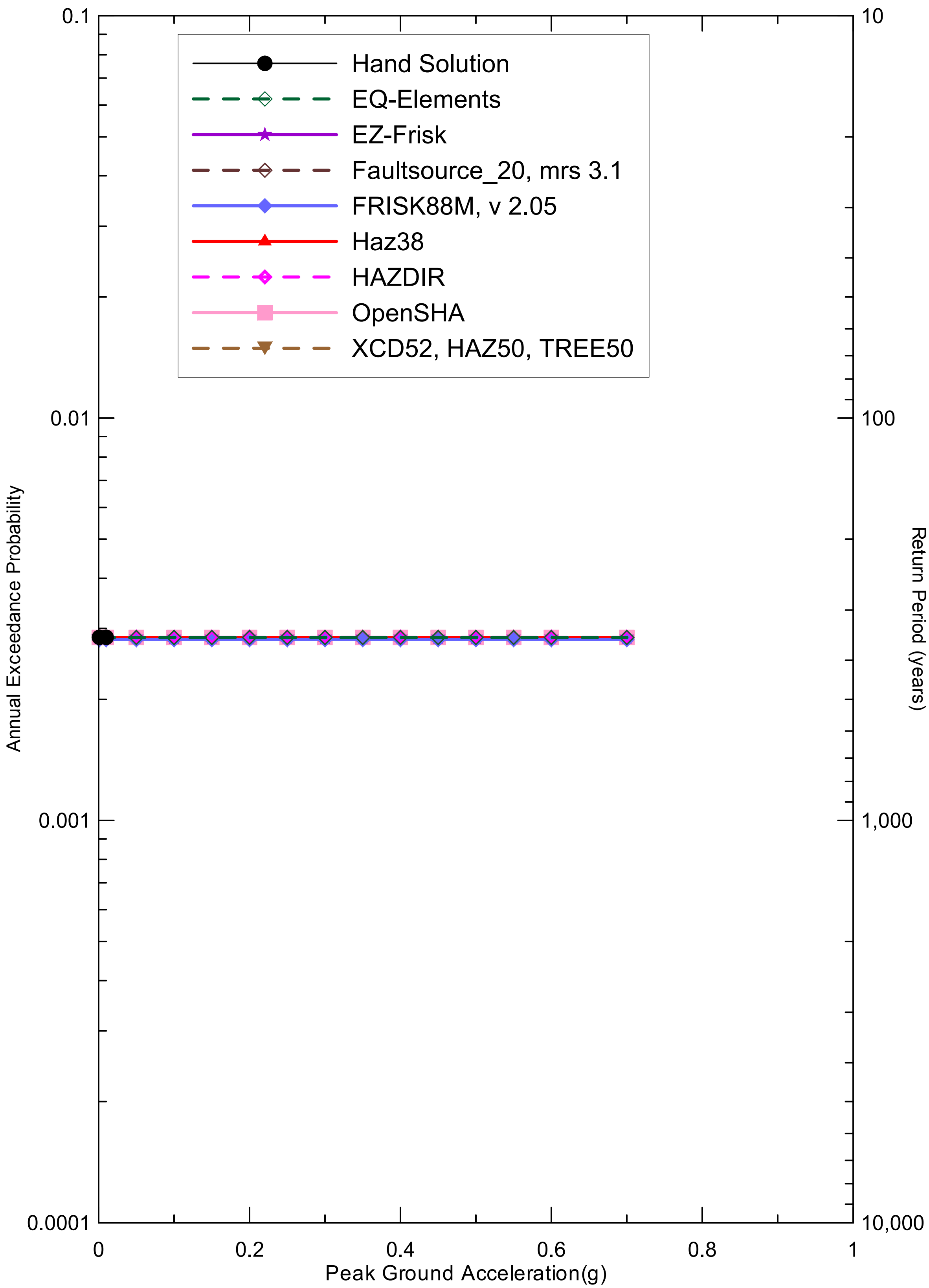
Figure 3.2



	PEER PSHA VERIFICATION	TEST SET 1, CASE 1, SITE 2	Figure 3.3



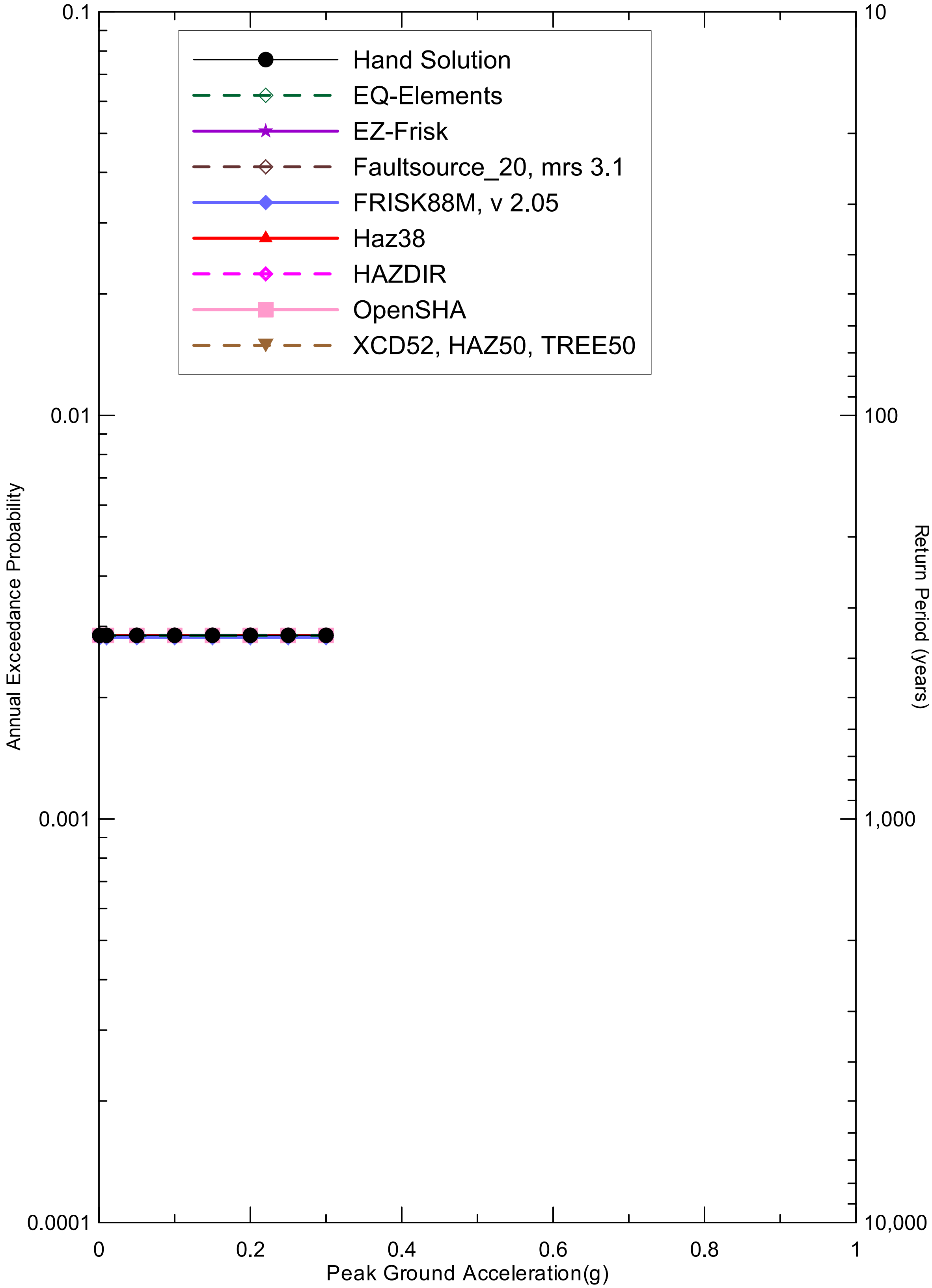
	PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 3	Figure 3.4



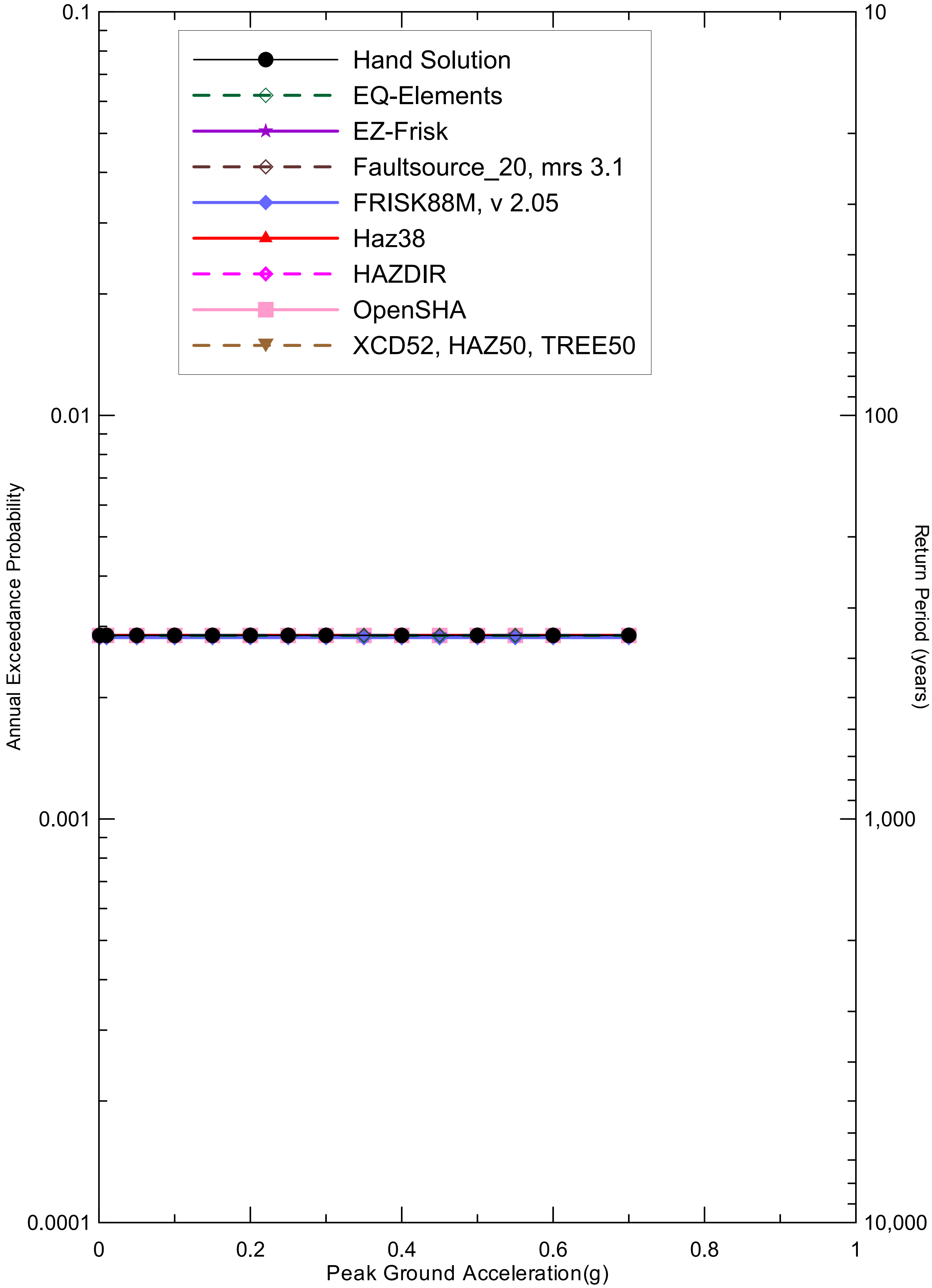
PEER PSHA VERIFICATION

TEST SET 1, CASE 1, SITE 4

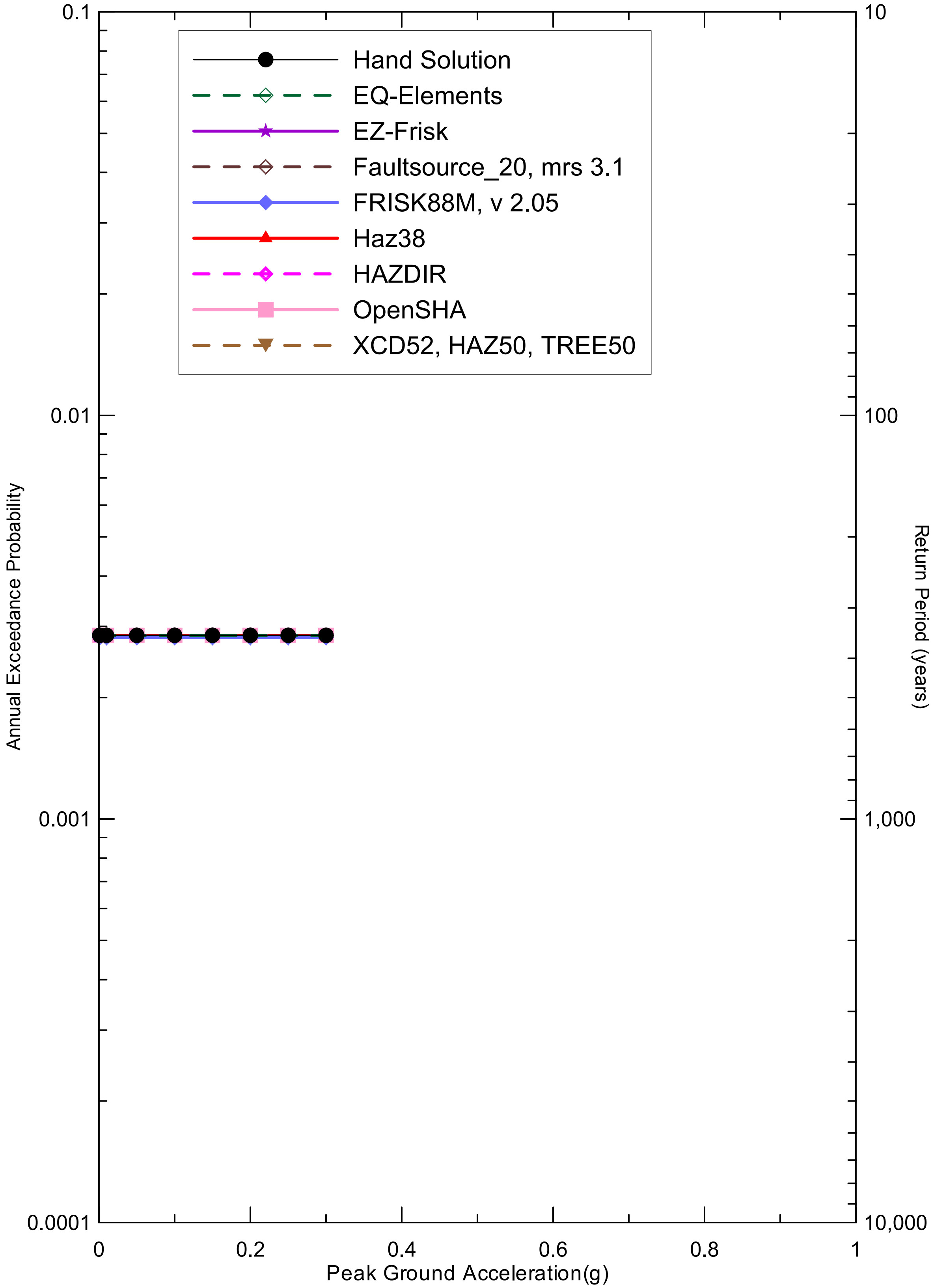
Figure 3.5



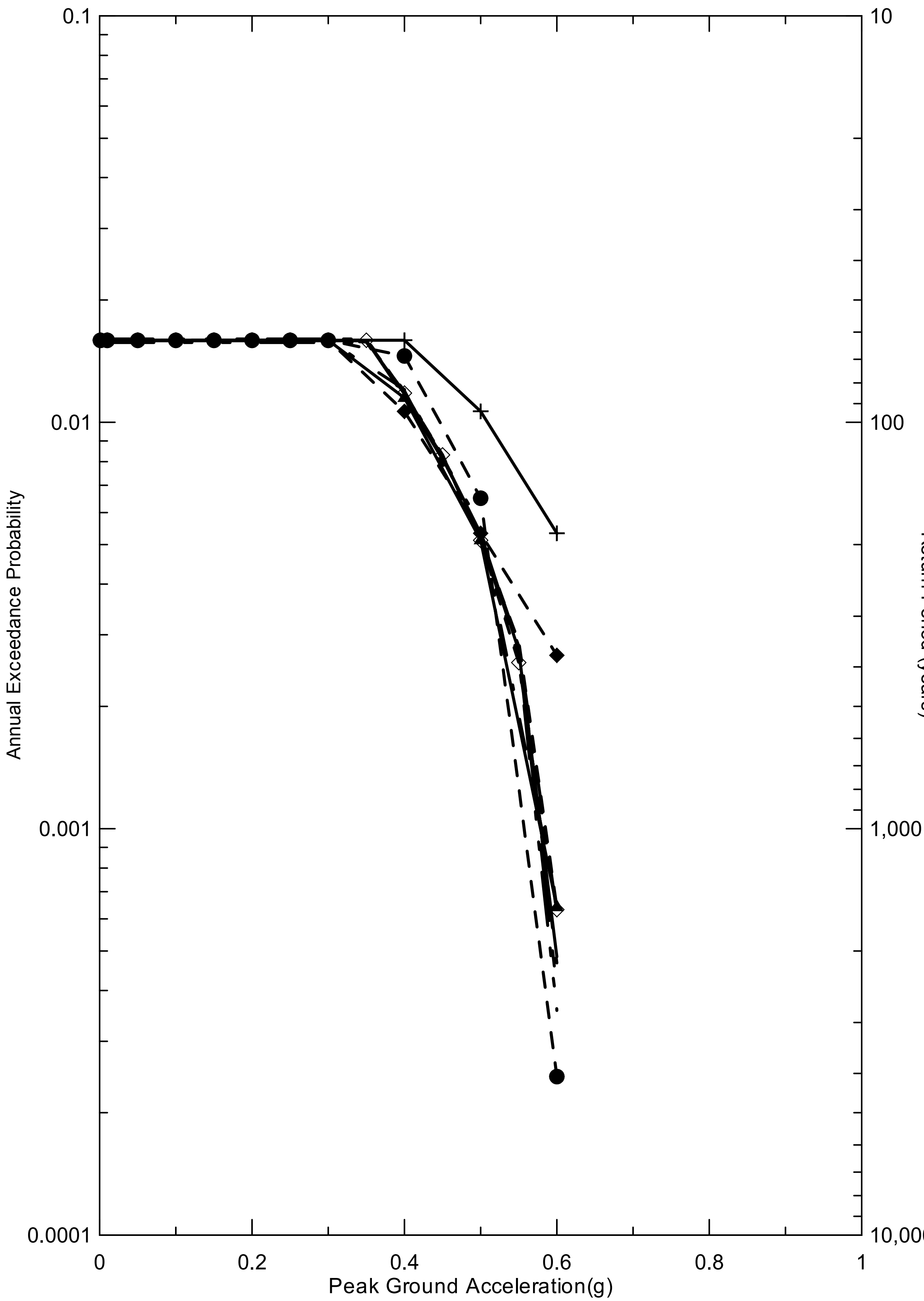
	PEER PSHA VERIFICATION	TEST SET 1, CASE 1, SITE 5	Figure 3.6



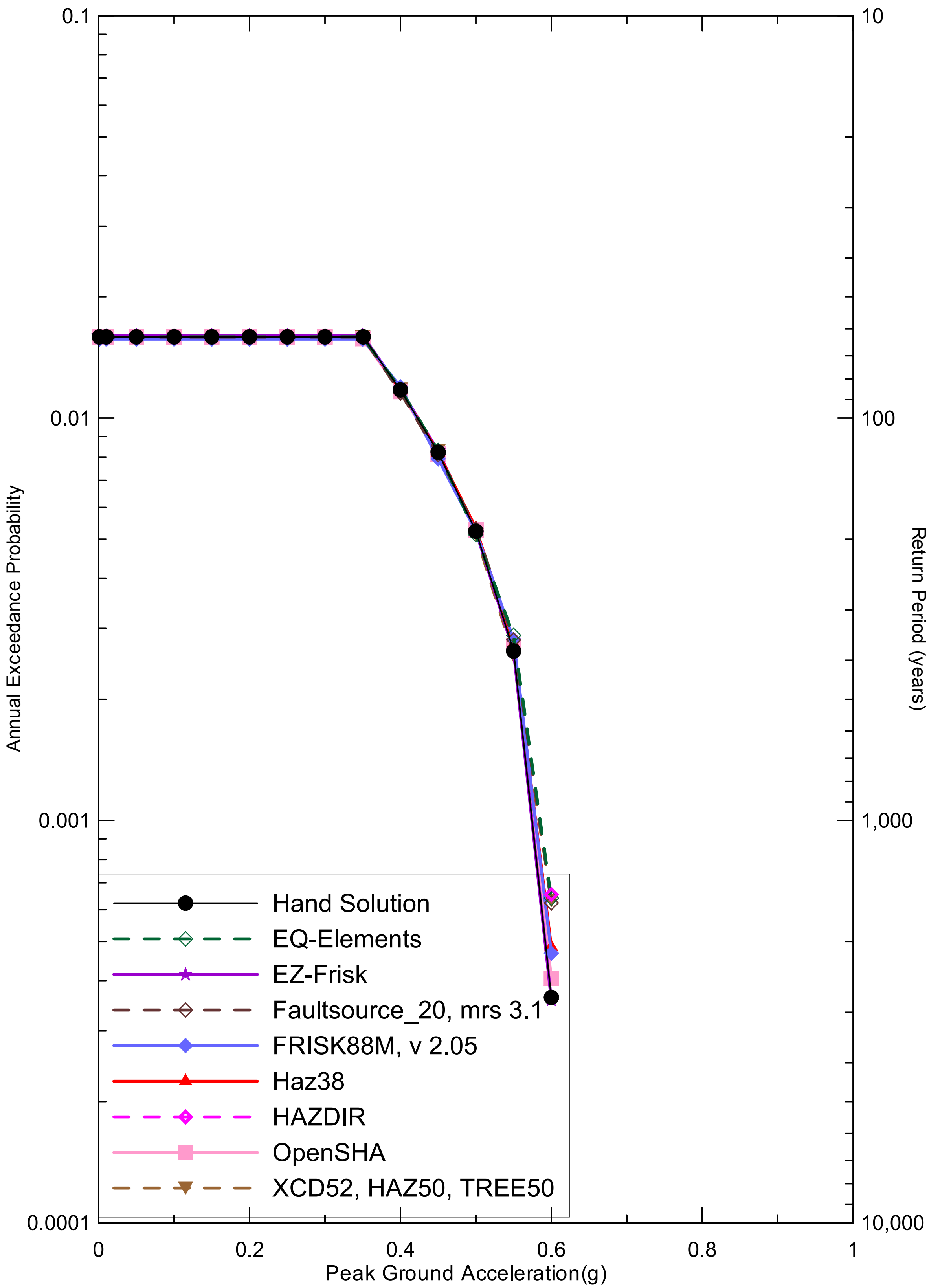
	PEER PSHA VERIFICATION	TEST SET 1, CASE 1, SITE 6	Figure 3.7



	PEER PSHA VERIFICATION	TEST SET 1, CASE 1, SITE 7	Figure 3.8



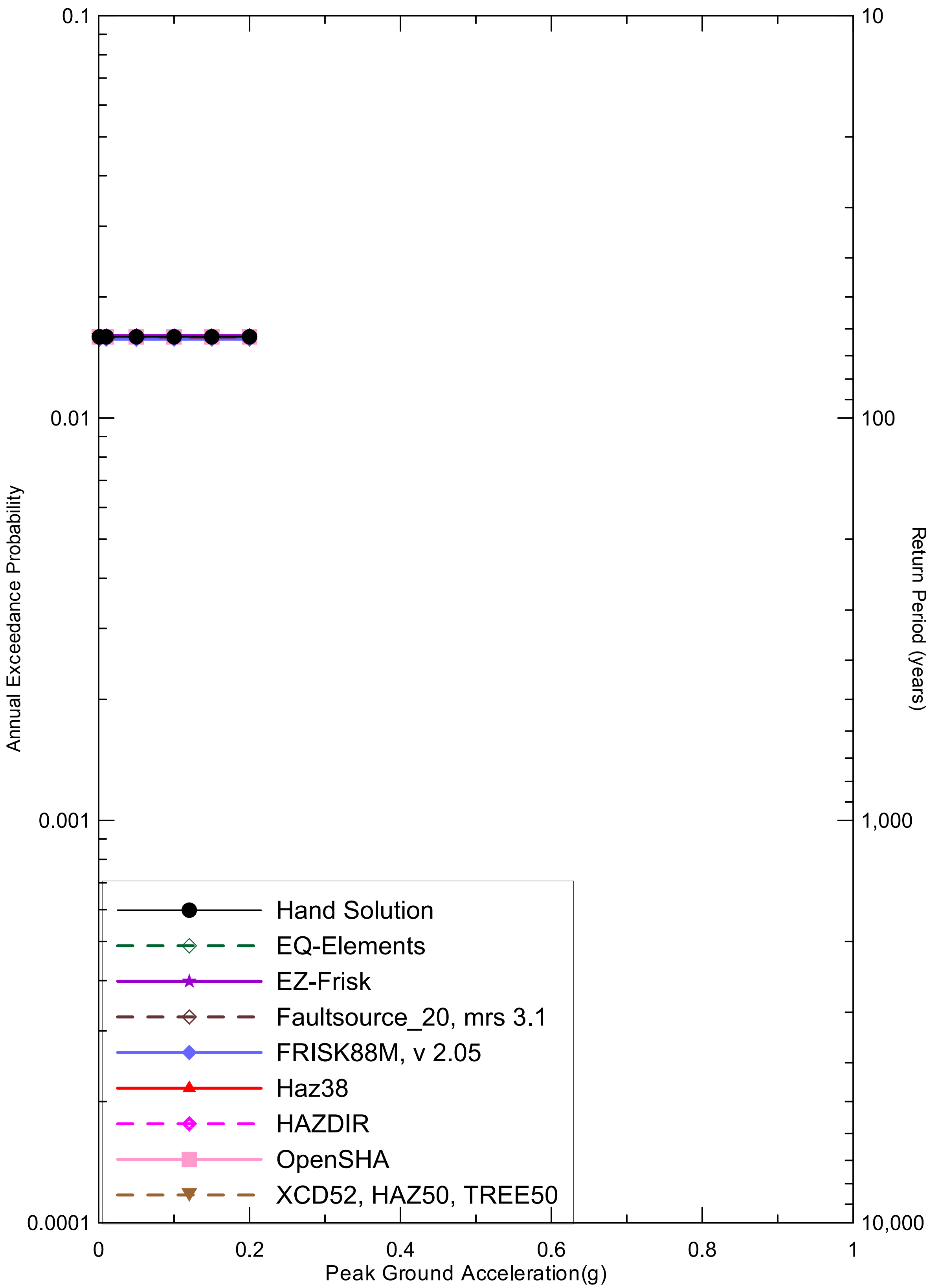
	PEER PSHA VERIFICATION	TEST SET 1, CASE 1, SITE 1 EARLY RESULTS	Figure 3.9



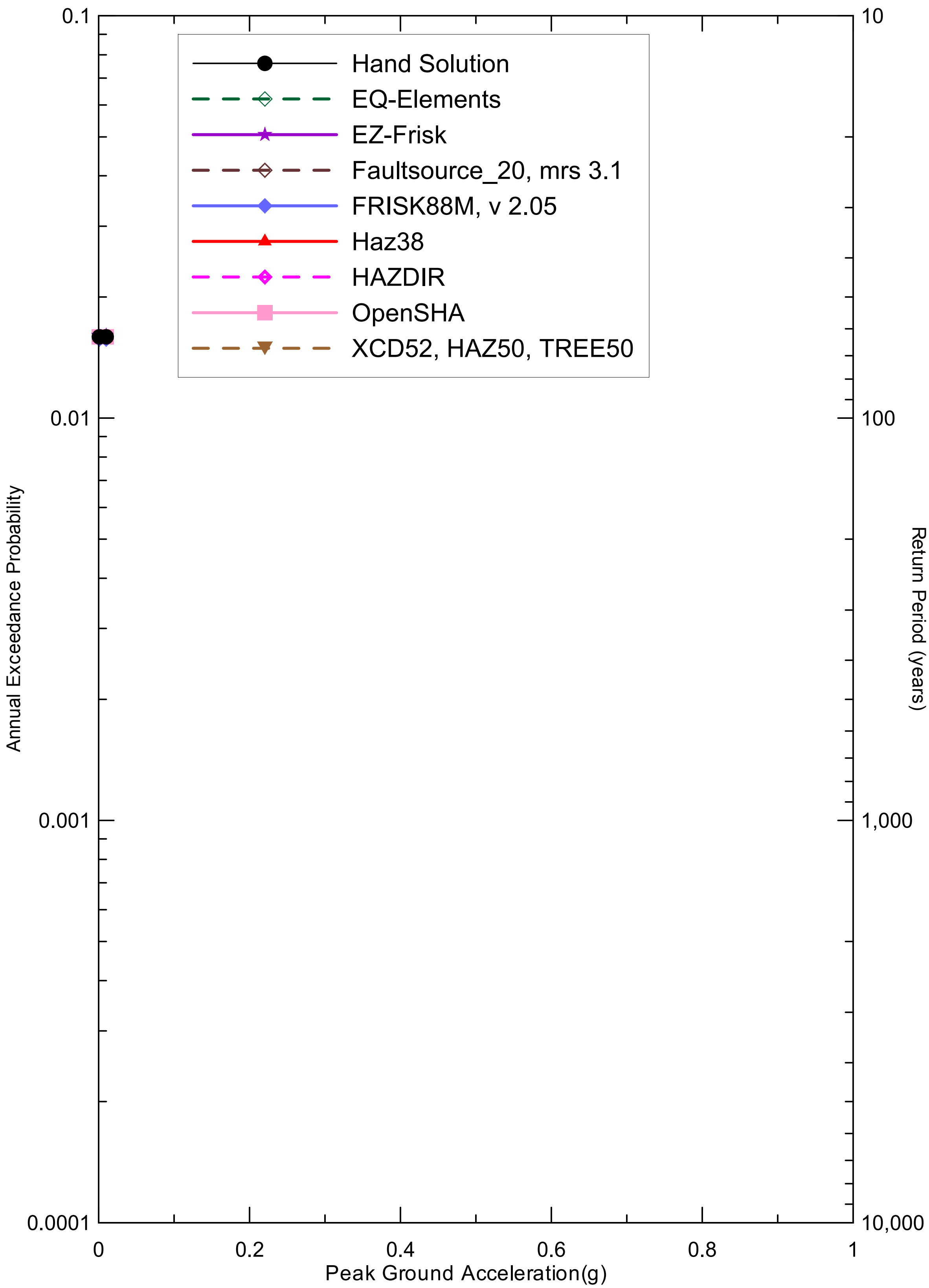
PEER PSHA VERIFICATION

TEST SET 1, CASE 2, SITE 1

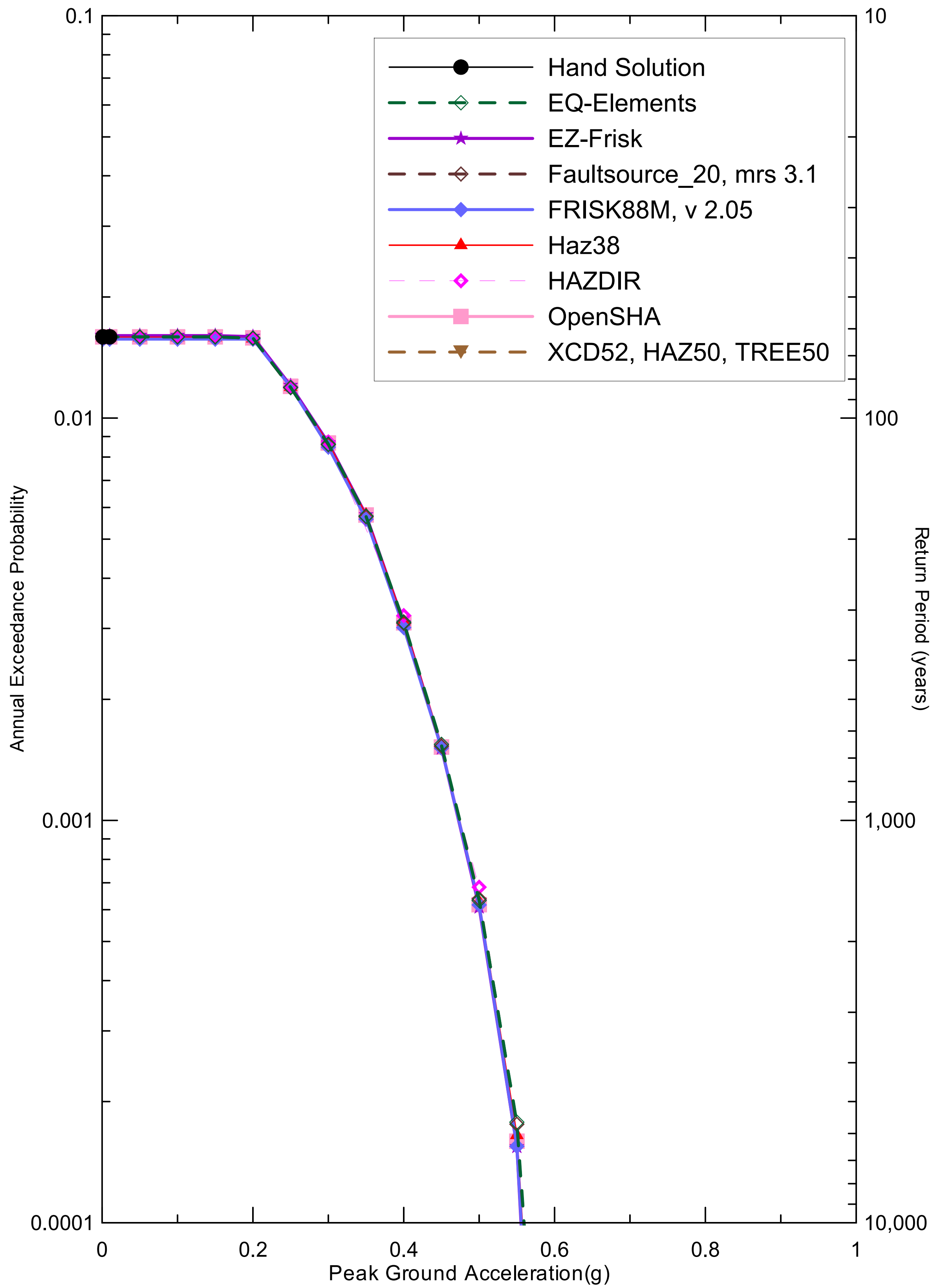
Figure 3.10



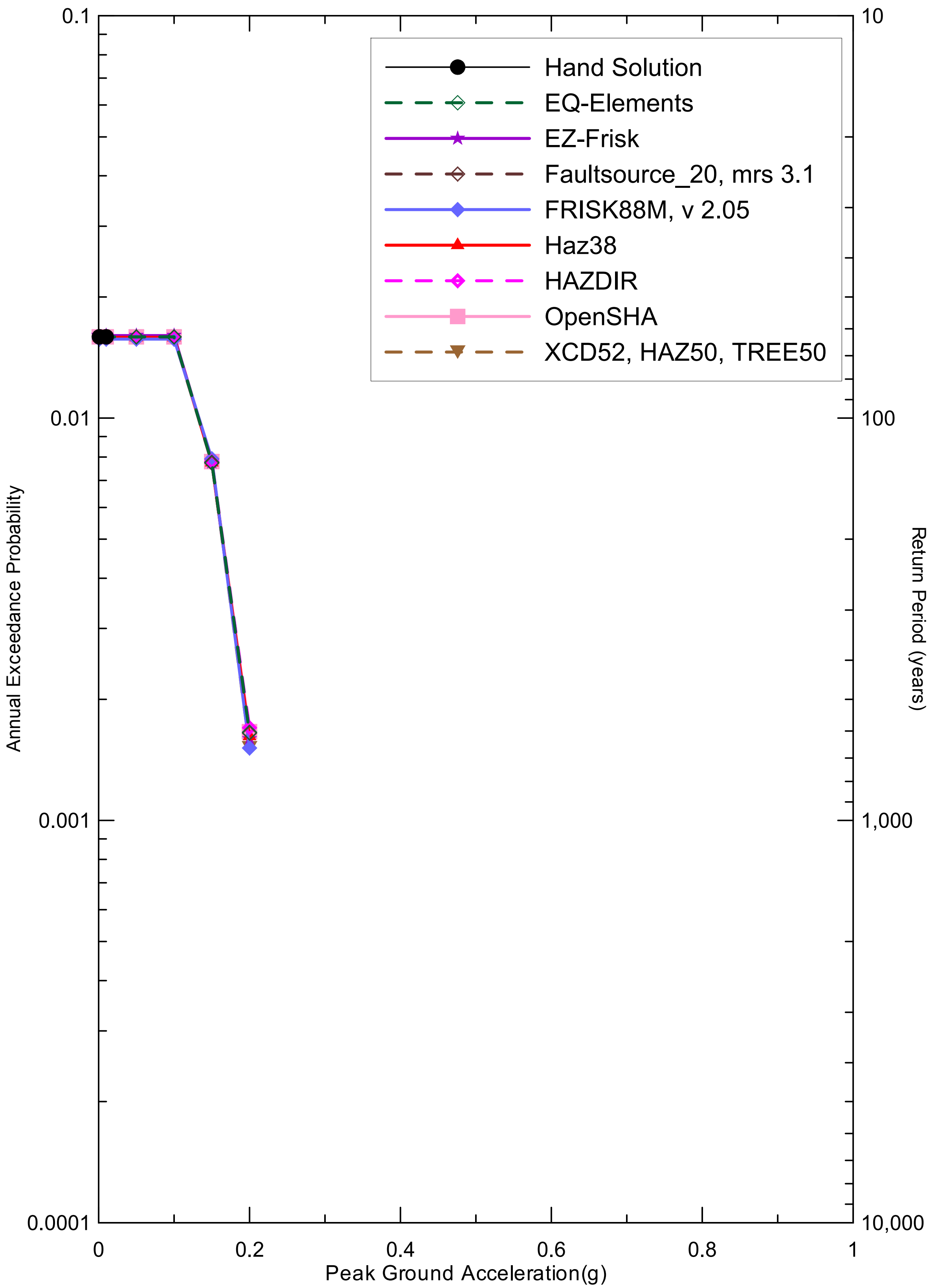
	PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 2	Figure 3.11



	PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 3	Figure 3.12



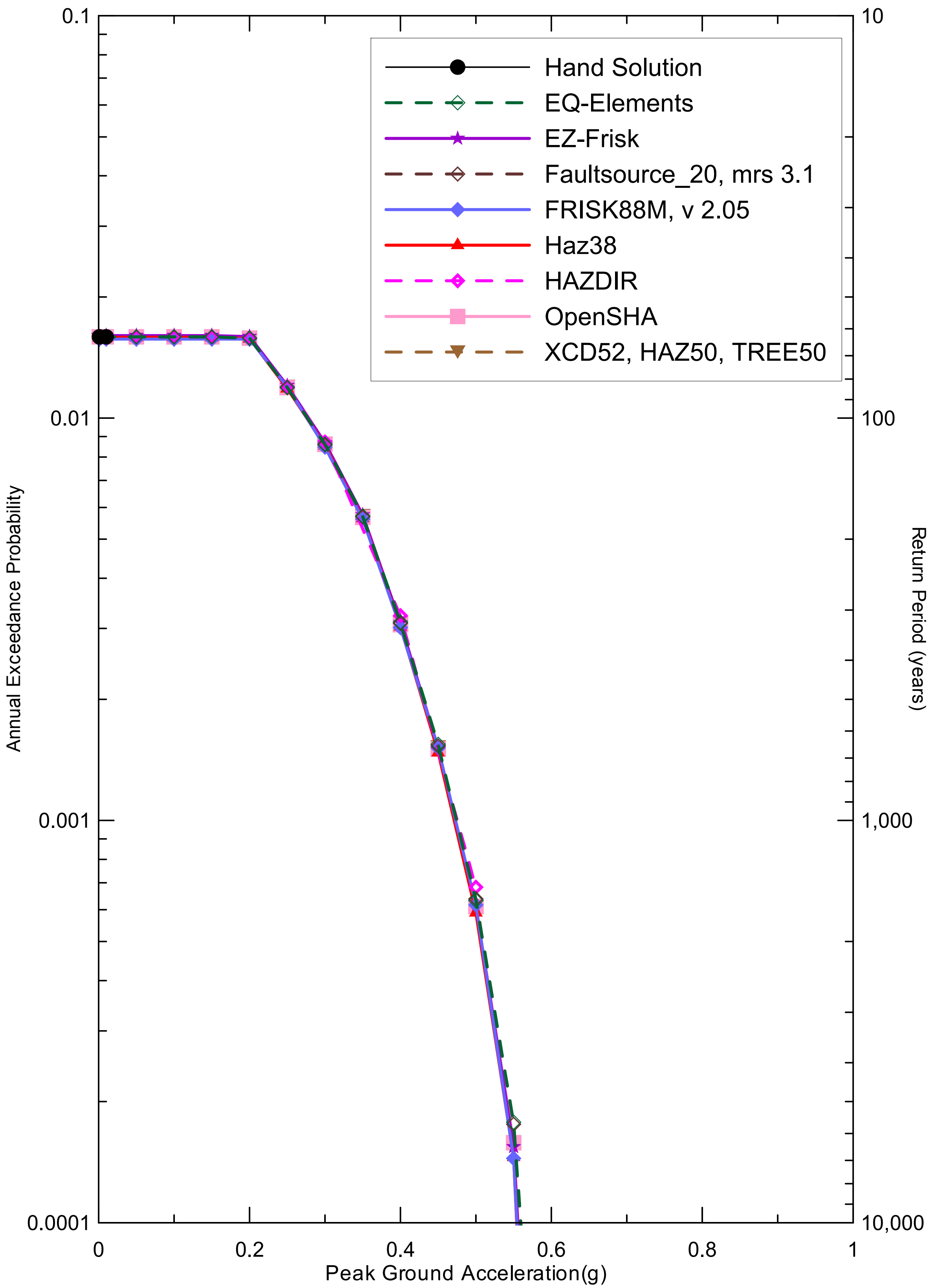
	PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 4	Figure 3.13



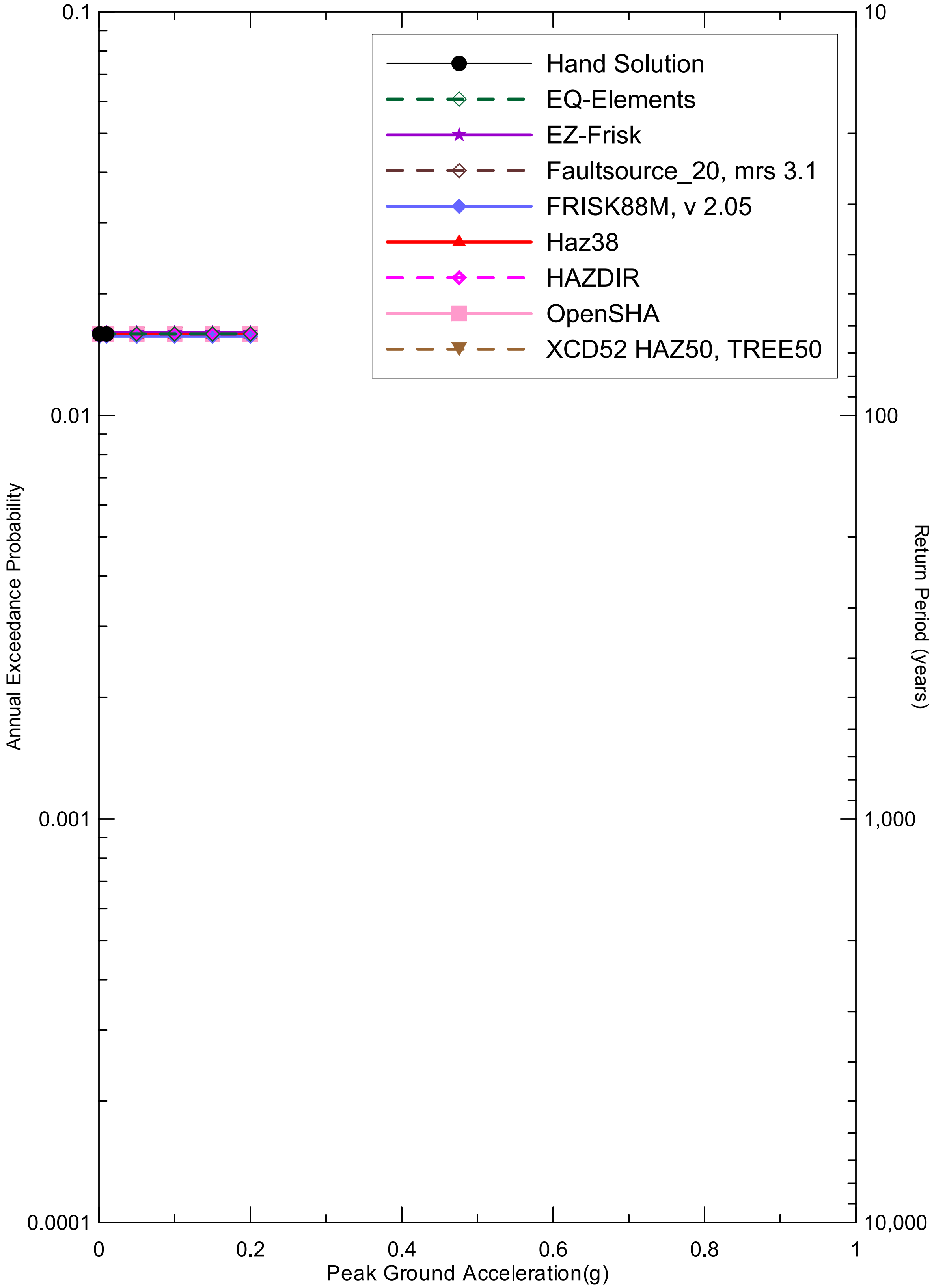
PEER PSHA VERIFICATION

TEST SET 1, CASE 2, SITE 5

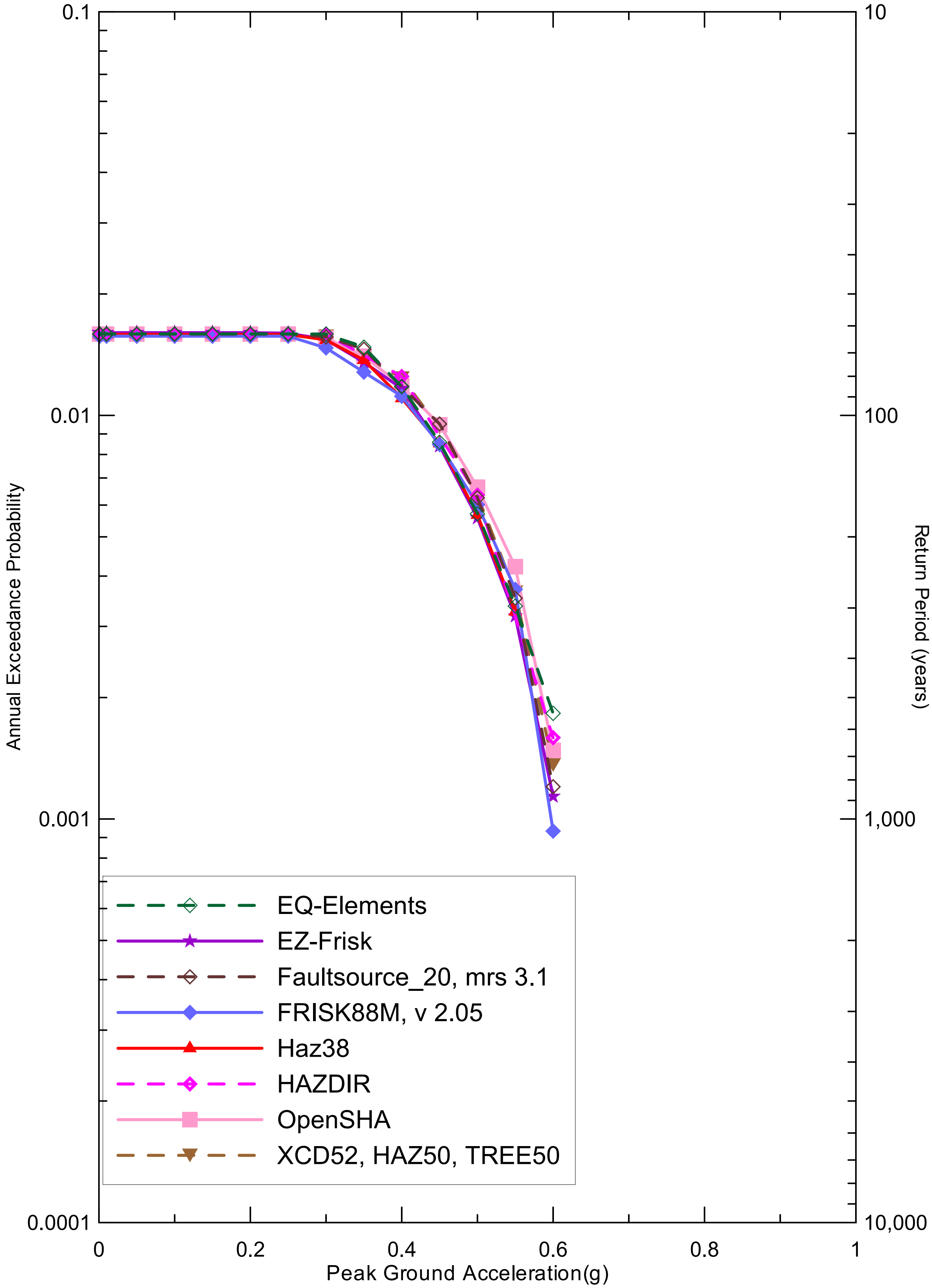
Figure 3.14



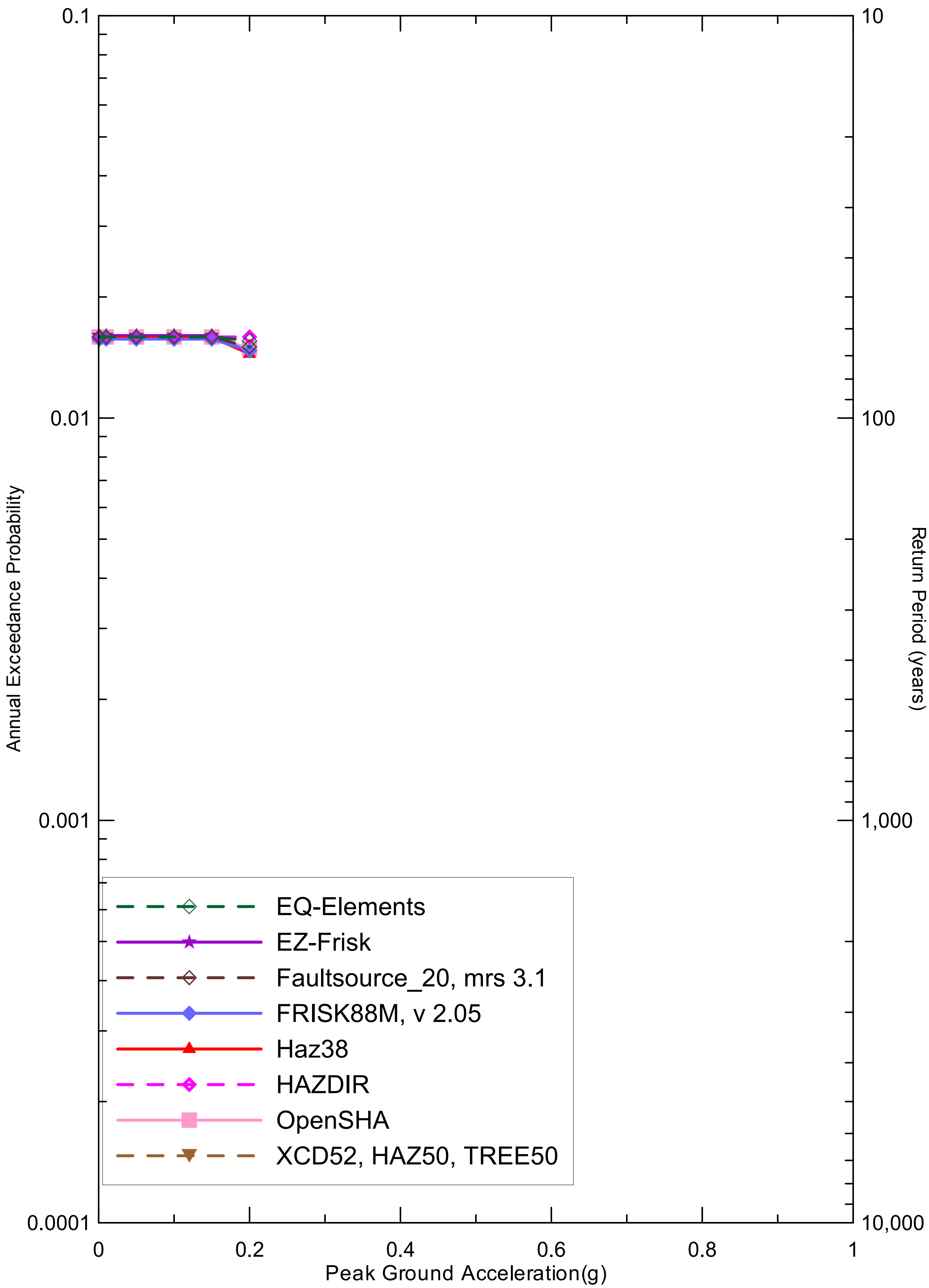
PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 6	Figure 3.15



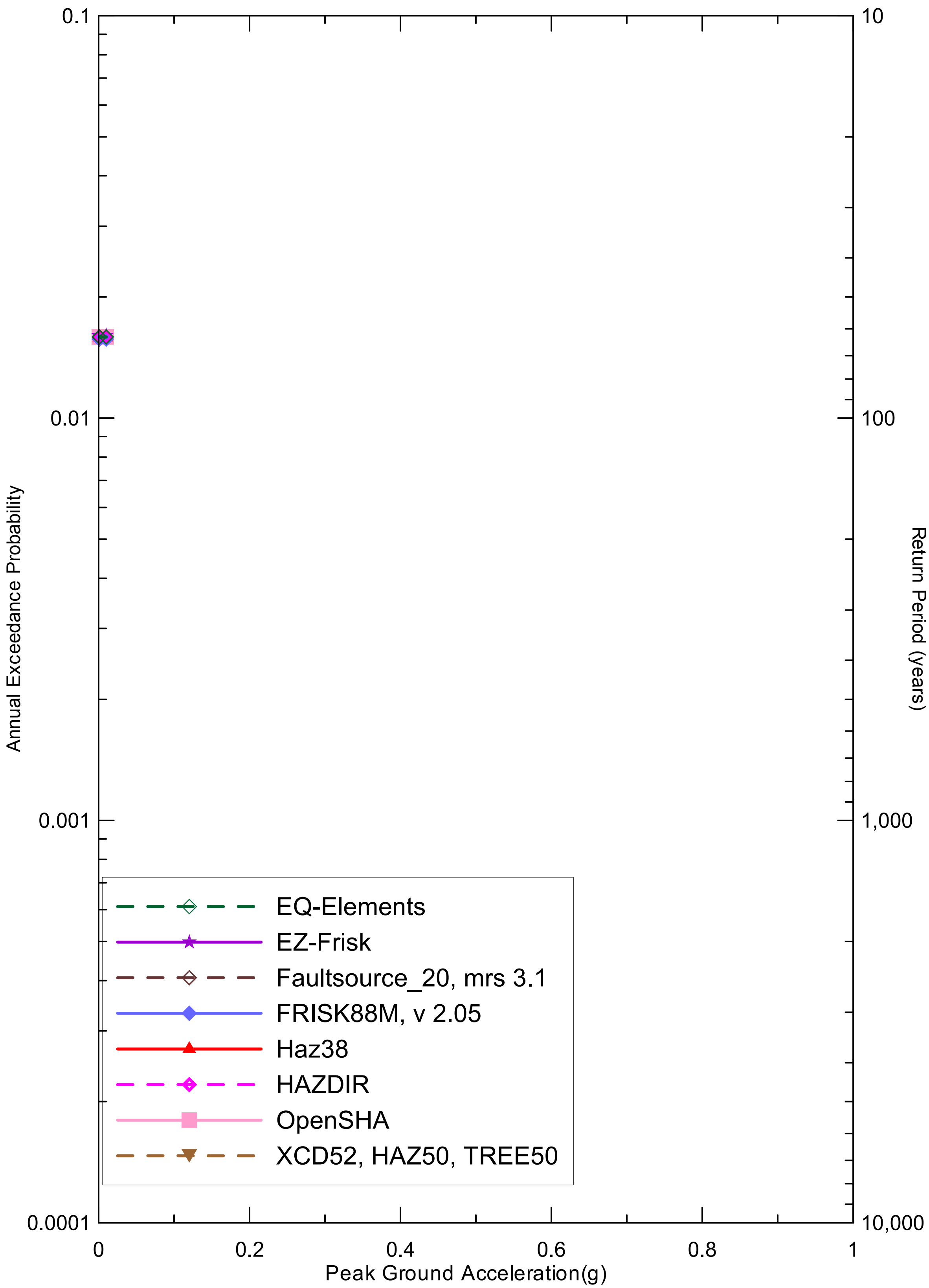
	PEER PSHA VERIFICATION	TEST SET 1, CASE 2, SITE 7	Figure 3.16



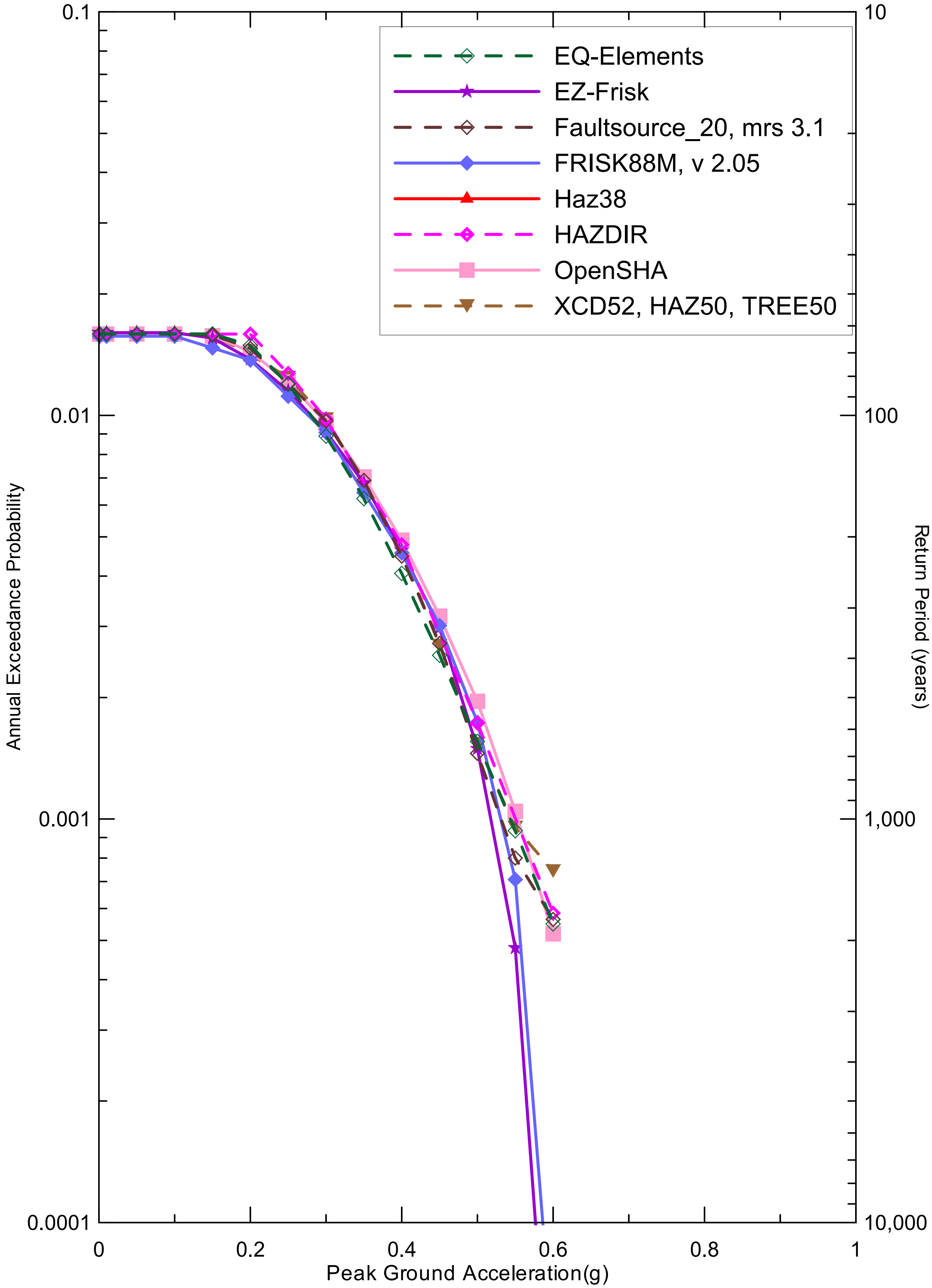
	PEER PSHA VERIFICATION	TEST SET 1, CASE 3, SITE 1	Figure 3.17



	PEER PSHA VERIFICATION	TEST SET 1, CASE 3, SITE 2	Figure 3.18



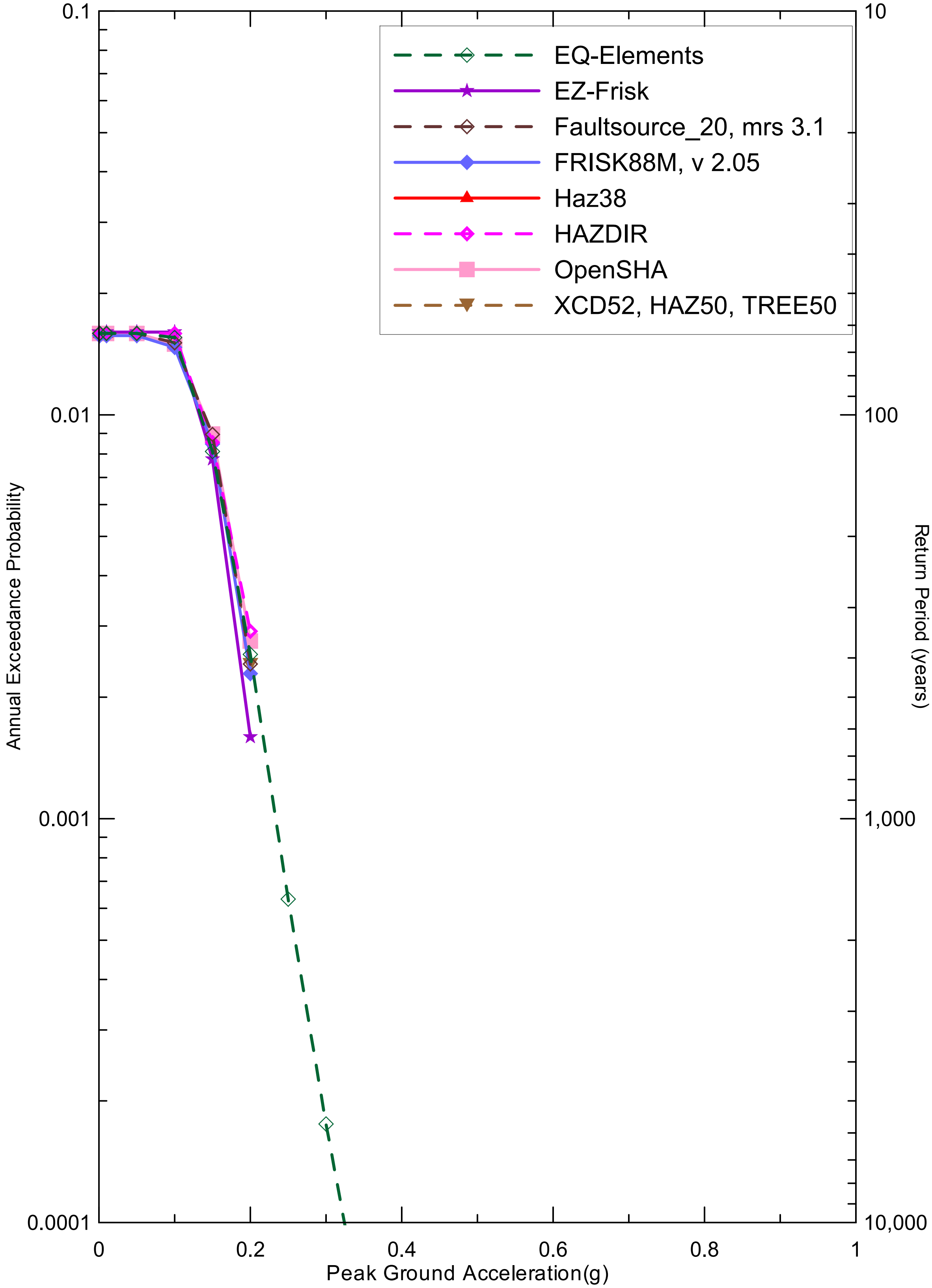
	PEER PSHA VERIFICATION	TEST SET 1, CASE 3, SITE 3	Figure 3.19



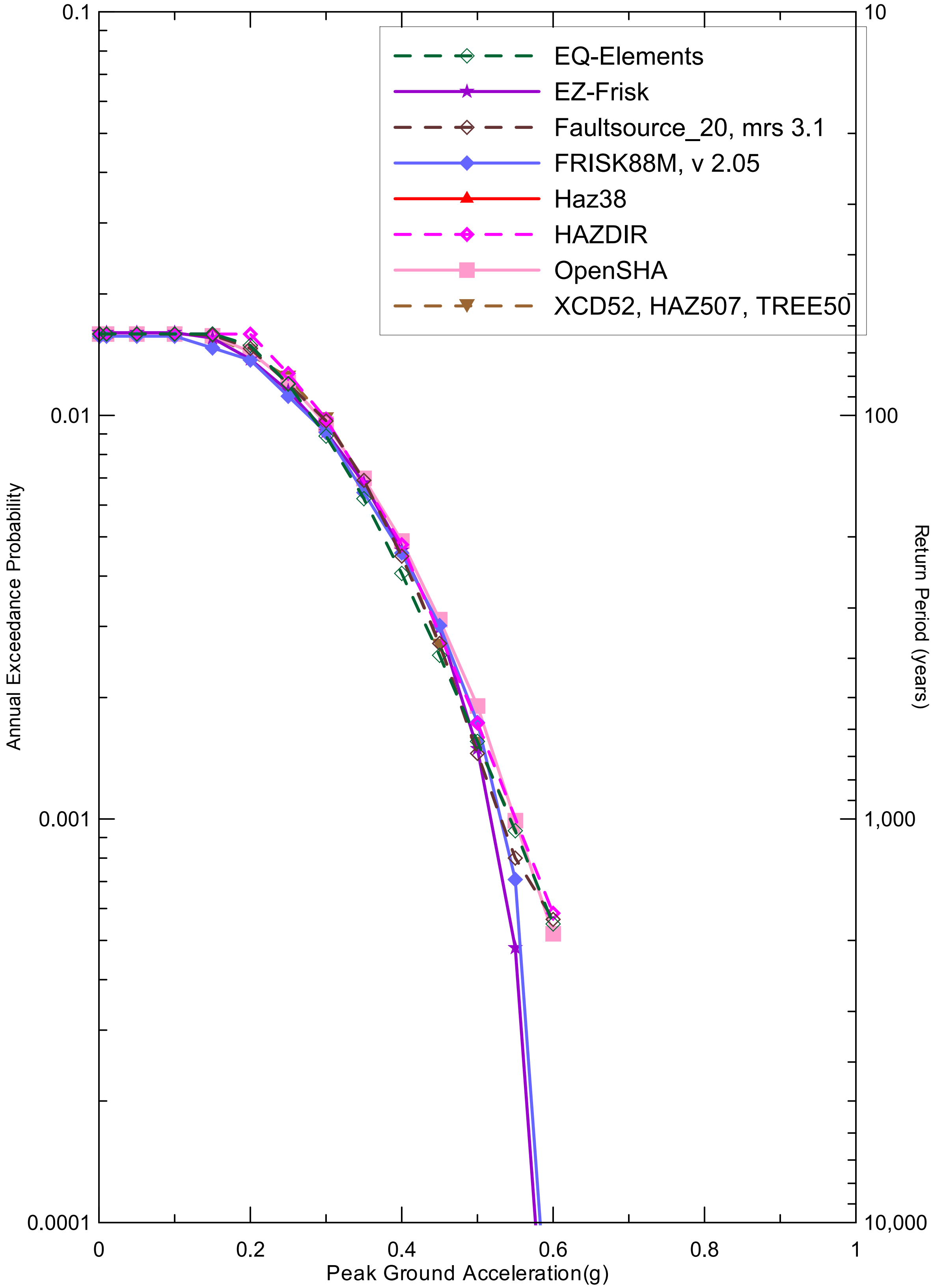
PEER PSHA VERIFICATION

TEST SET 1, CASE 3, SITE 4

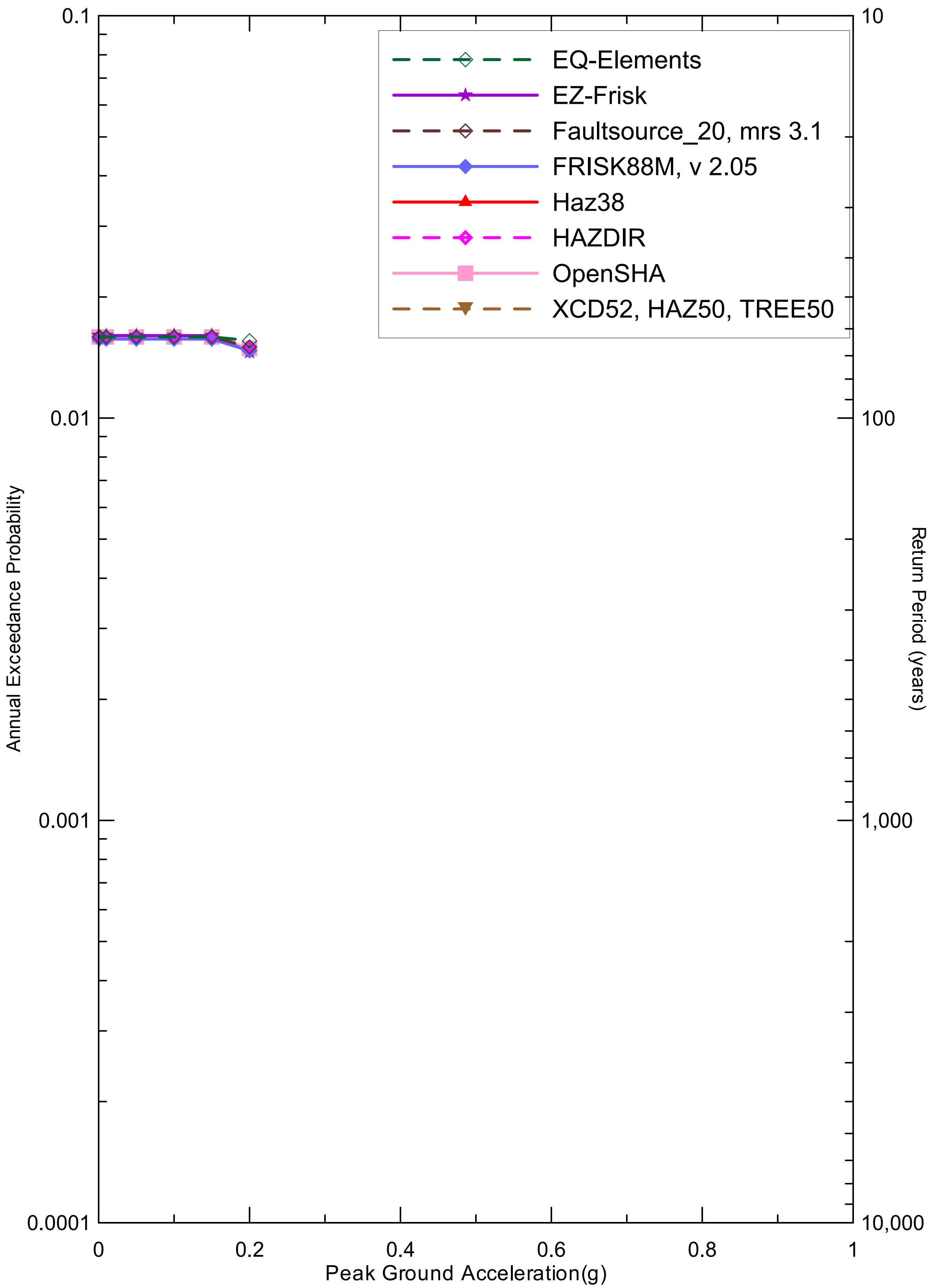
Figure 3.20



	PEER PSHA VERIFICATION	TEST SET 1, CASE 3, SITE 5	Figure 3.21



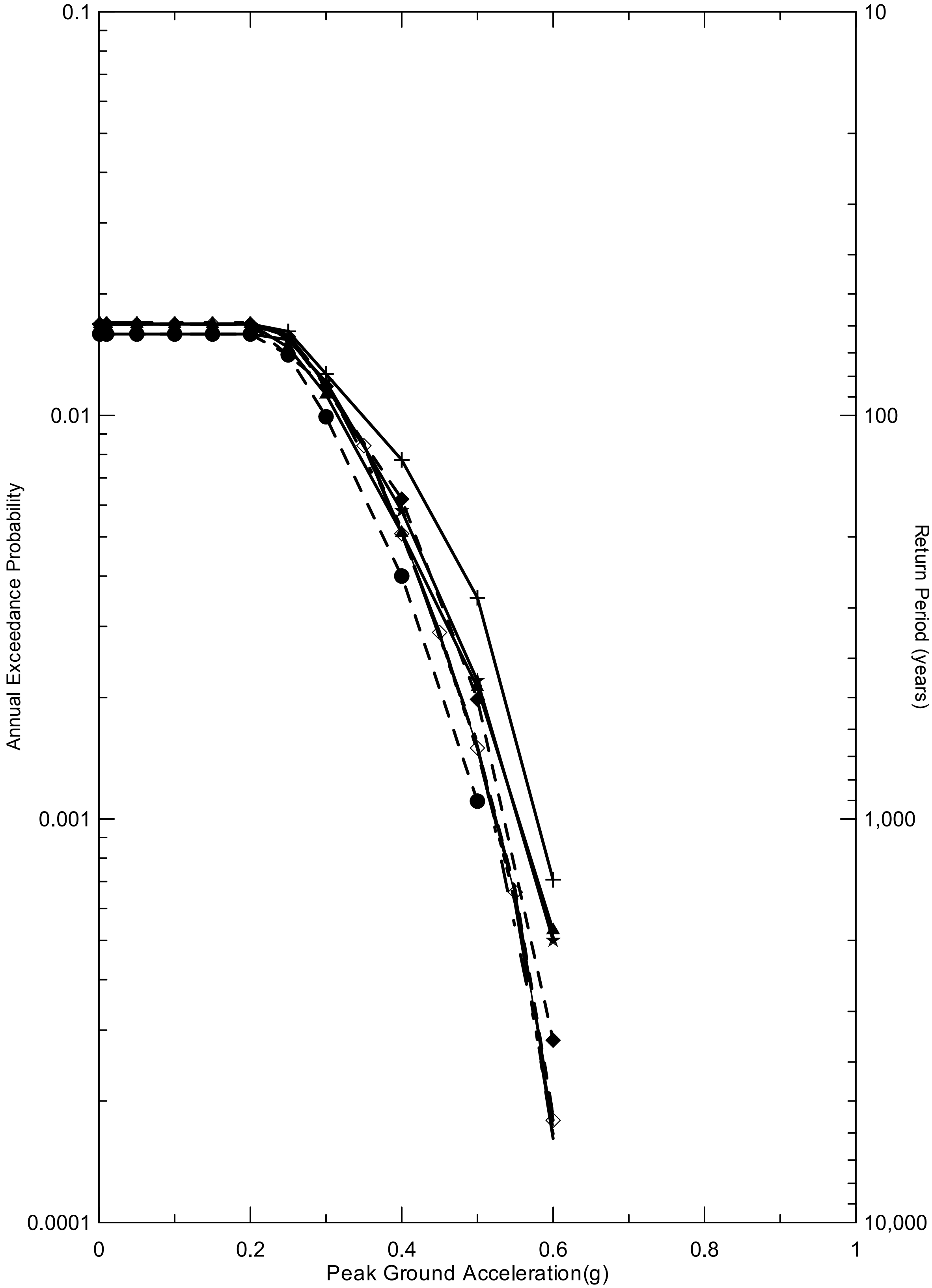
PEER PSHA VERIFICATION	TEST SET 1, CASE 3, SITE 6	Figure 3.22



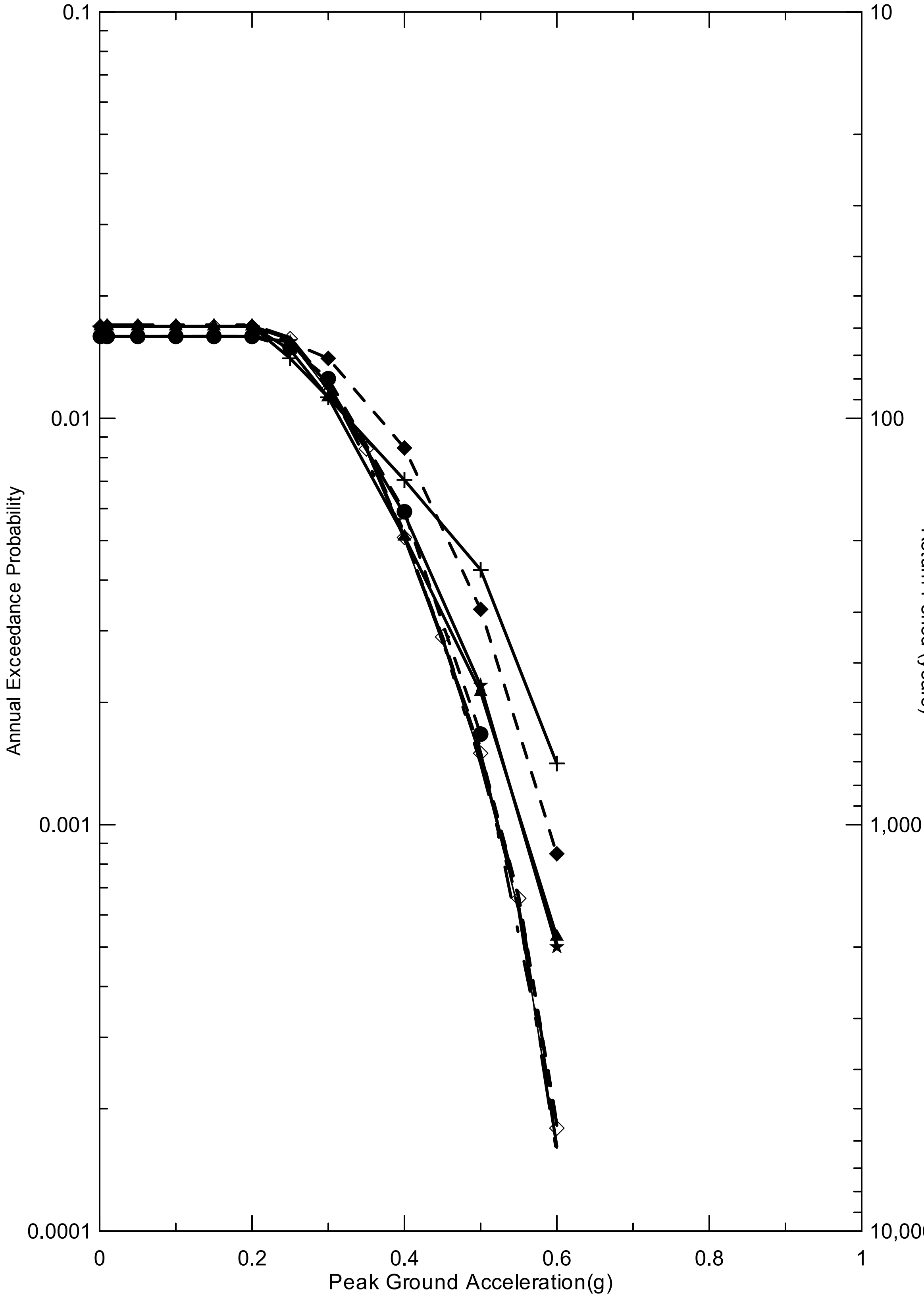
PEER PSHA VERIFICATION

TEST SET 1, CASE 3, SITE 7

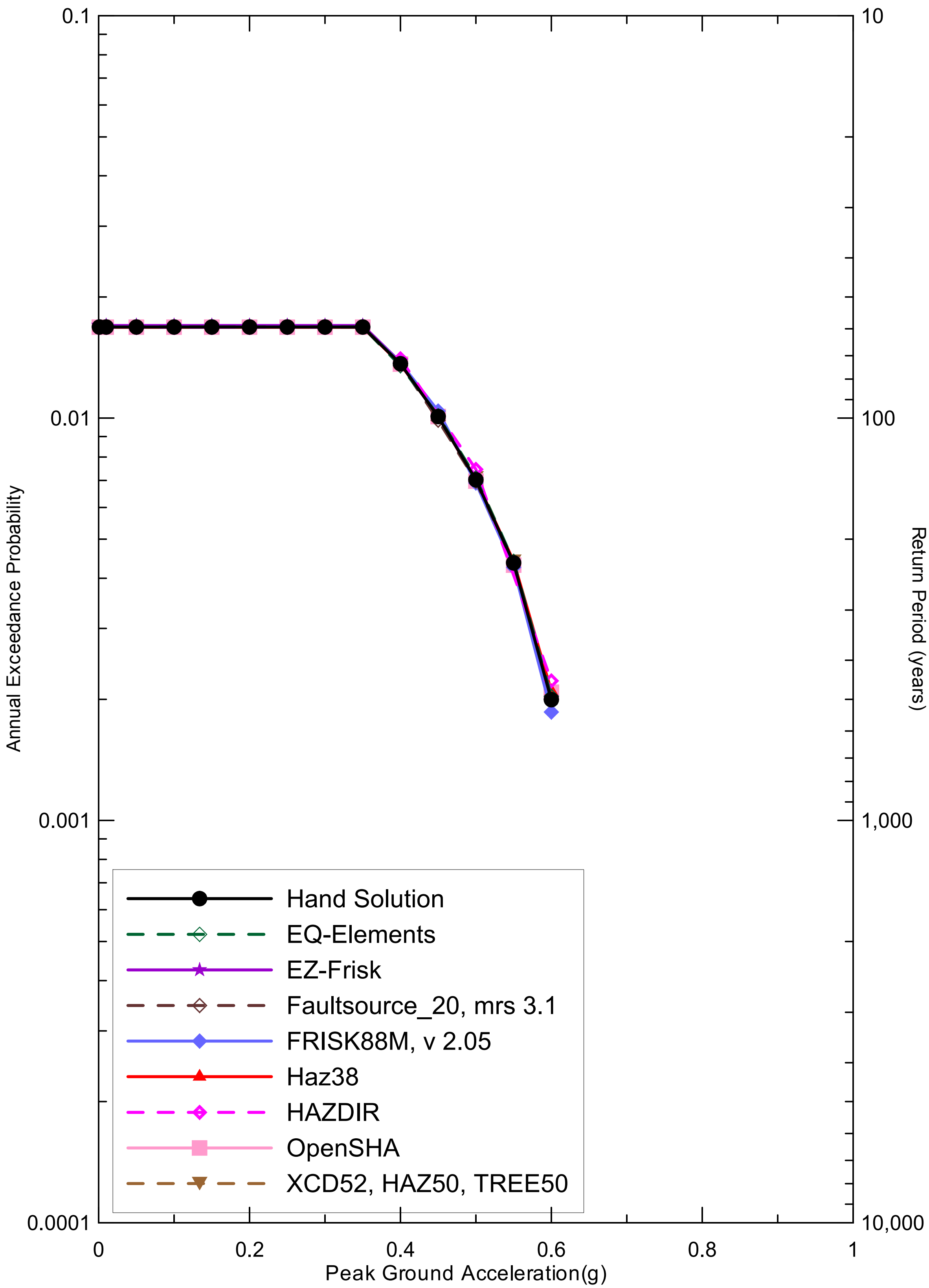
Figure 3.23



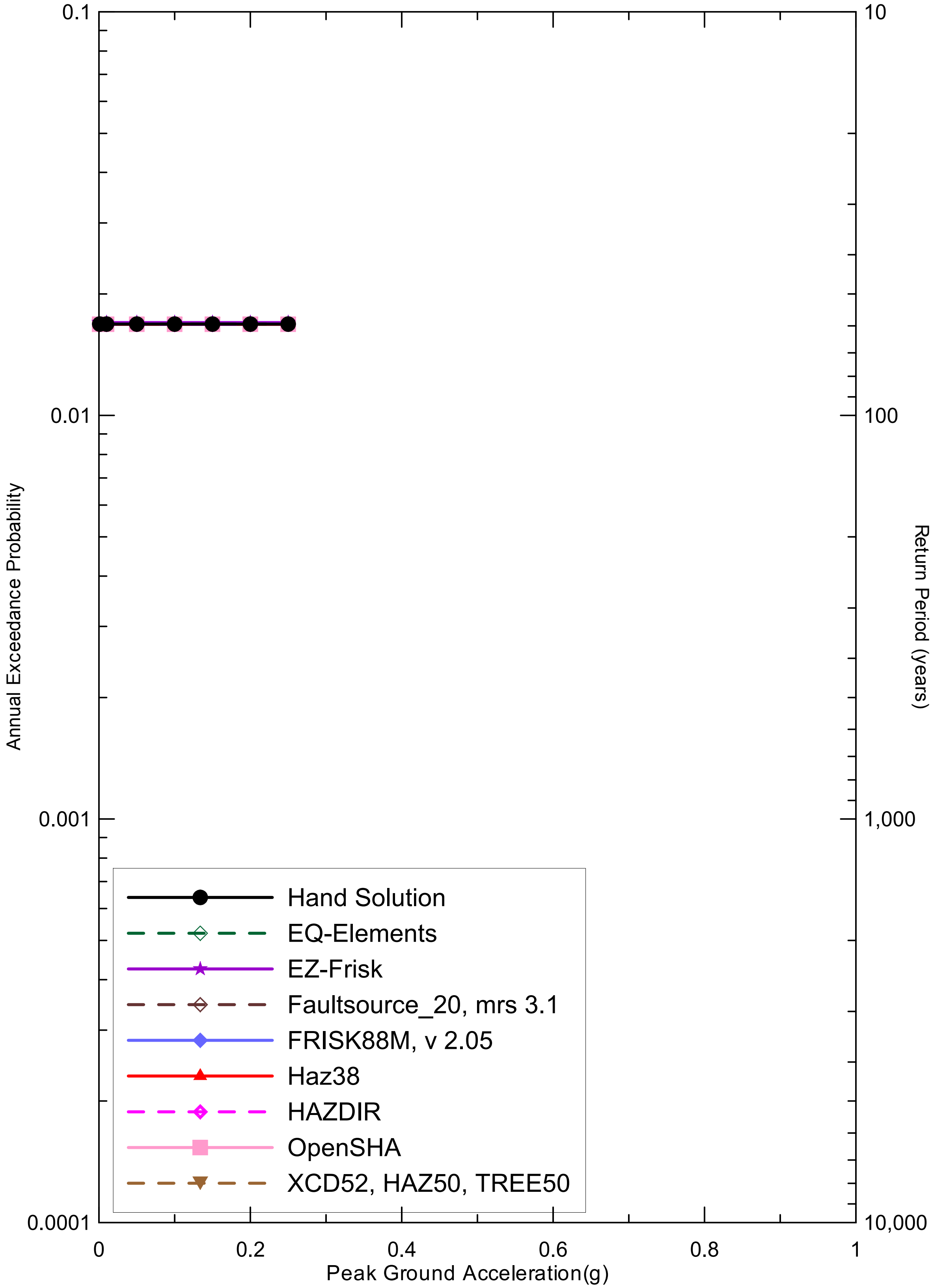
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 4 EARLY RESULTS	Figure 3.24



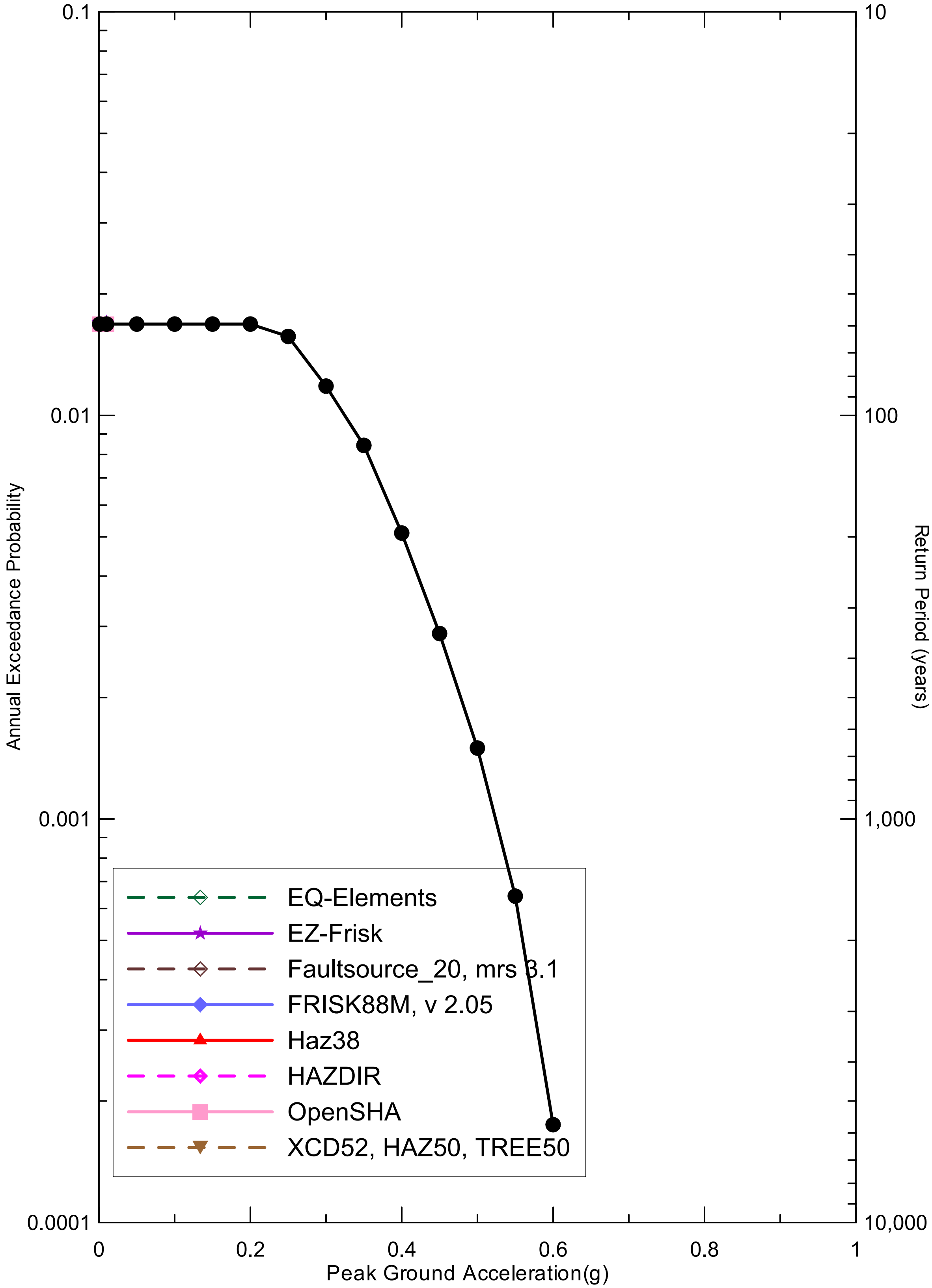
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 6 EARLY RESULTS	Figure 3.25



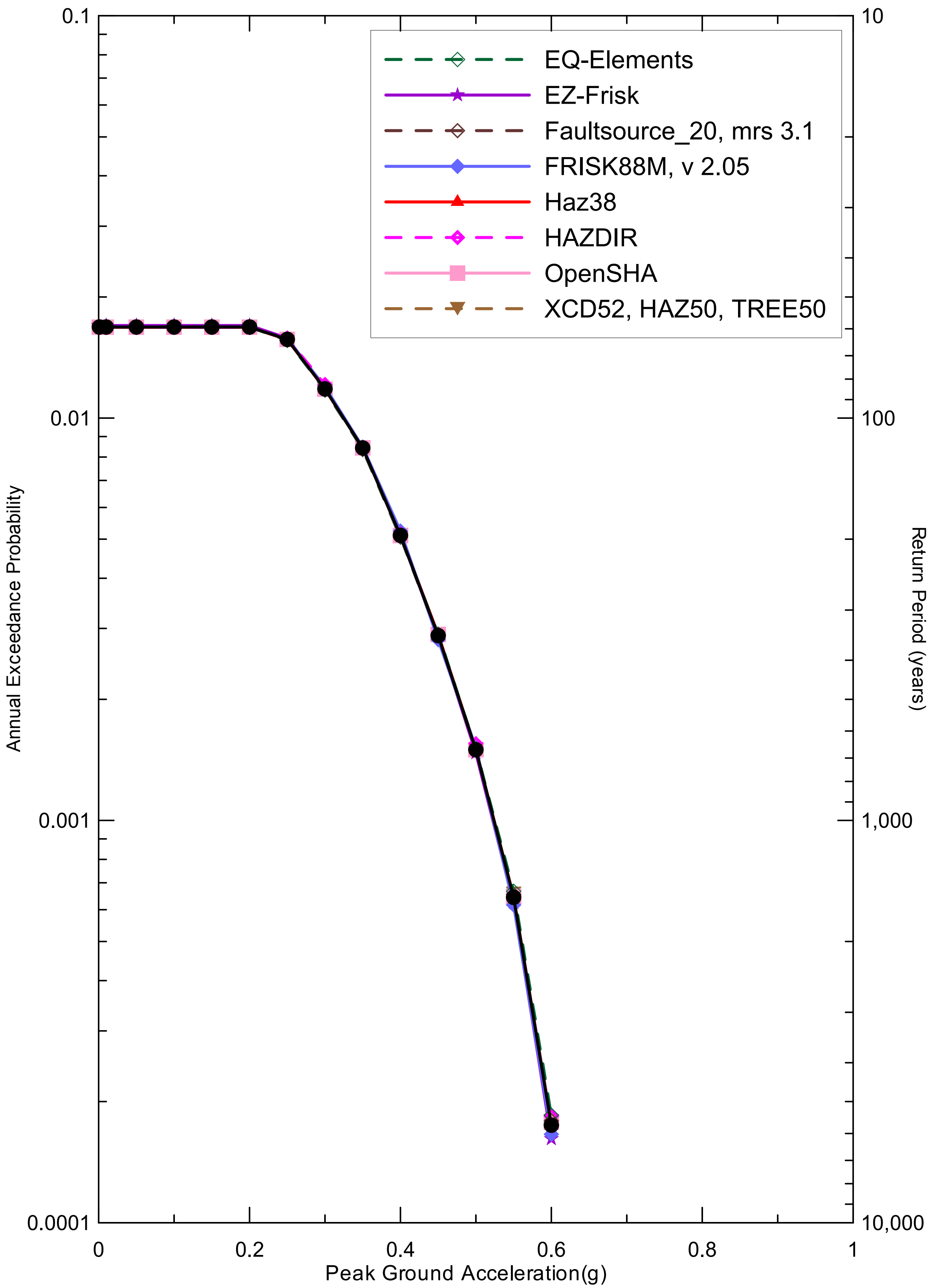
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 1	Figure 3.26



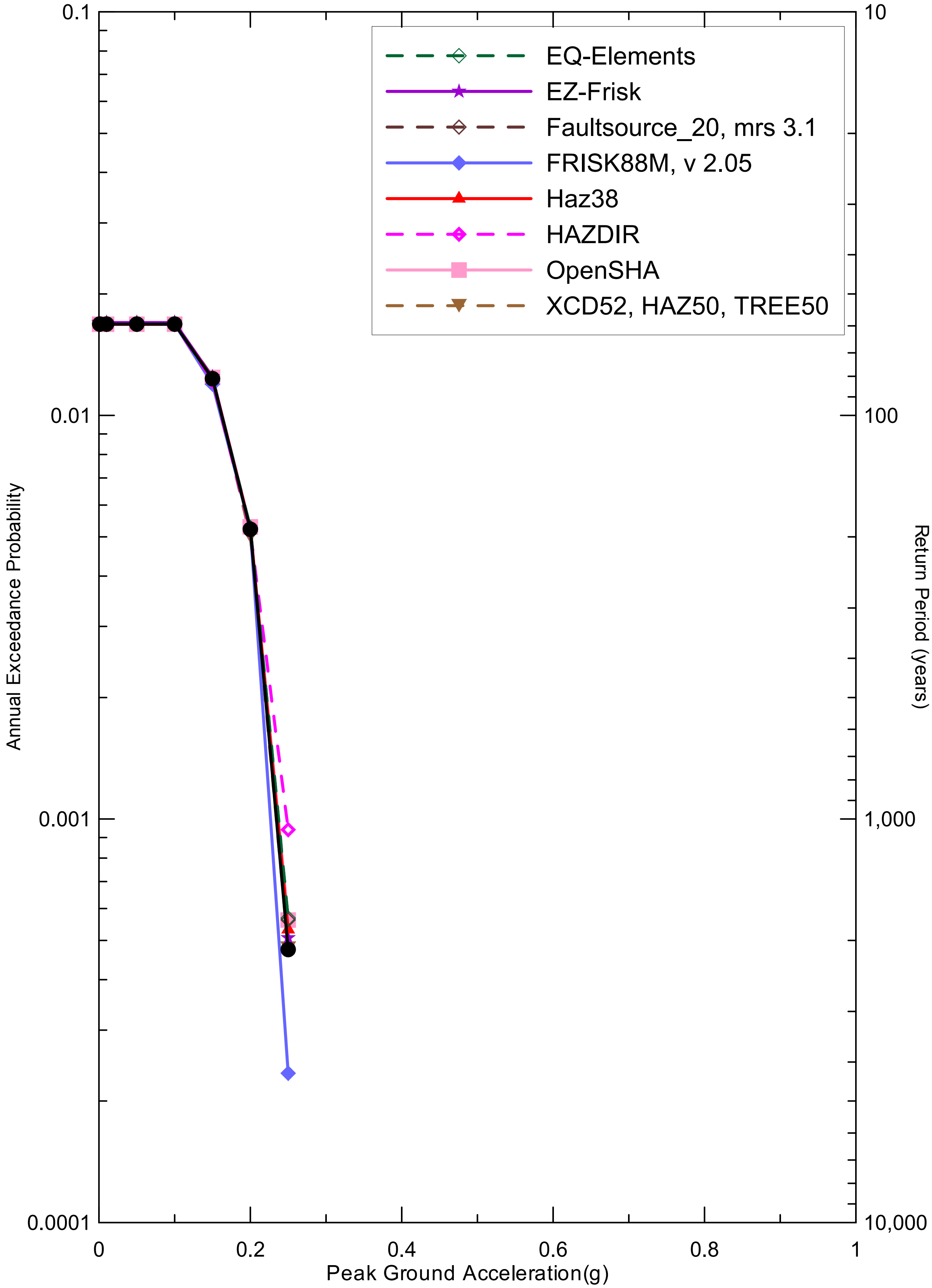
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 2	Figure 3.27



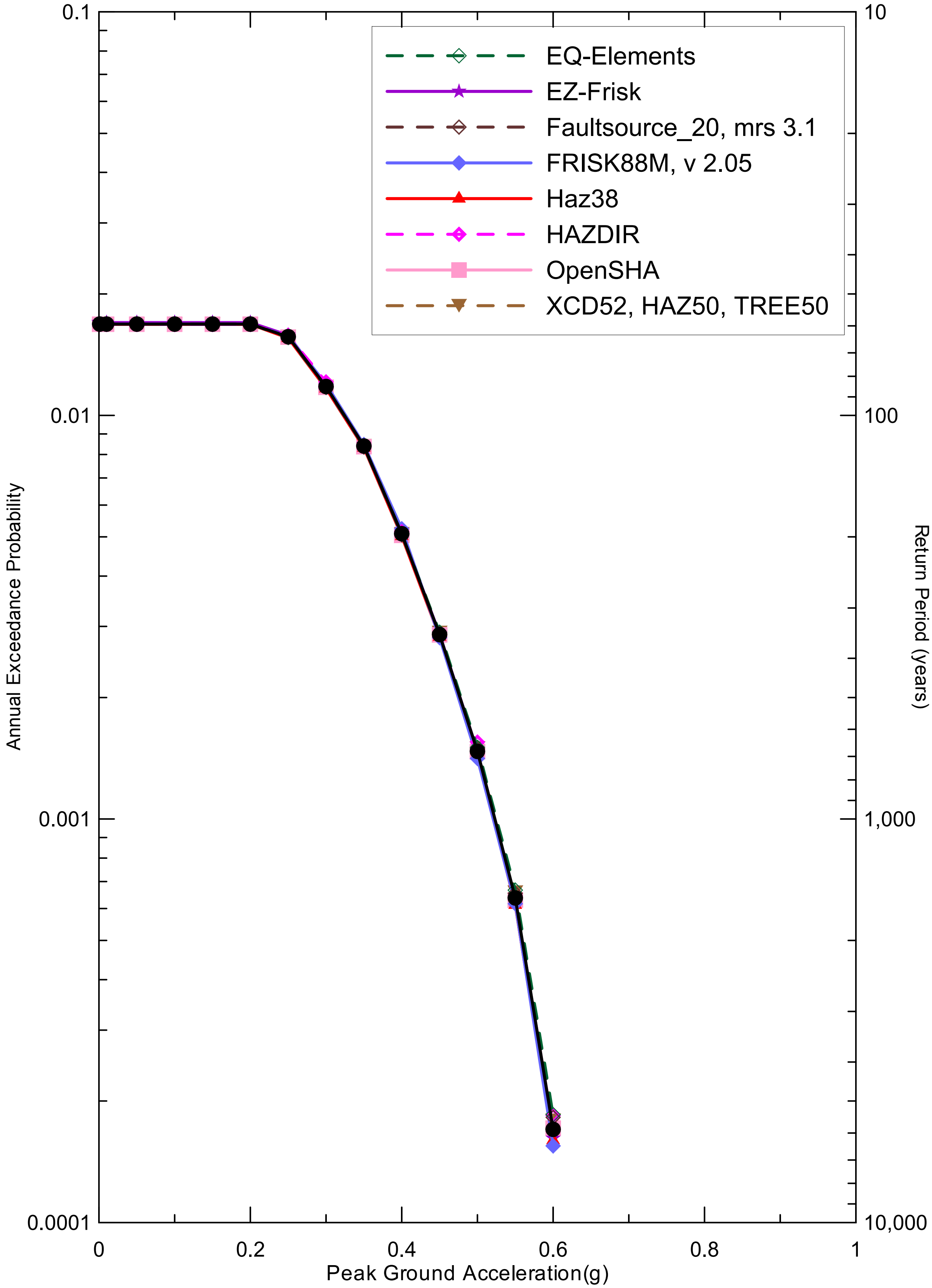
PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 3	Figure 3.28



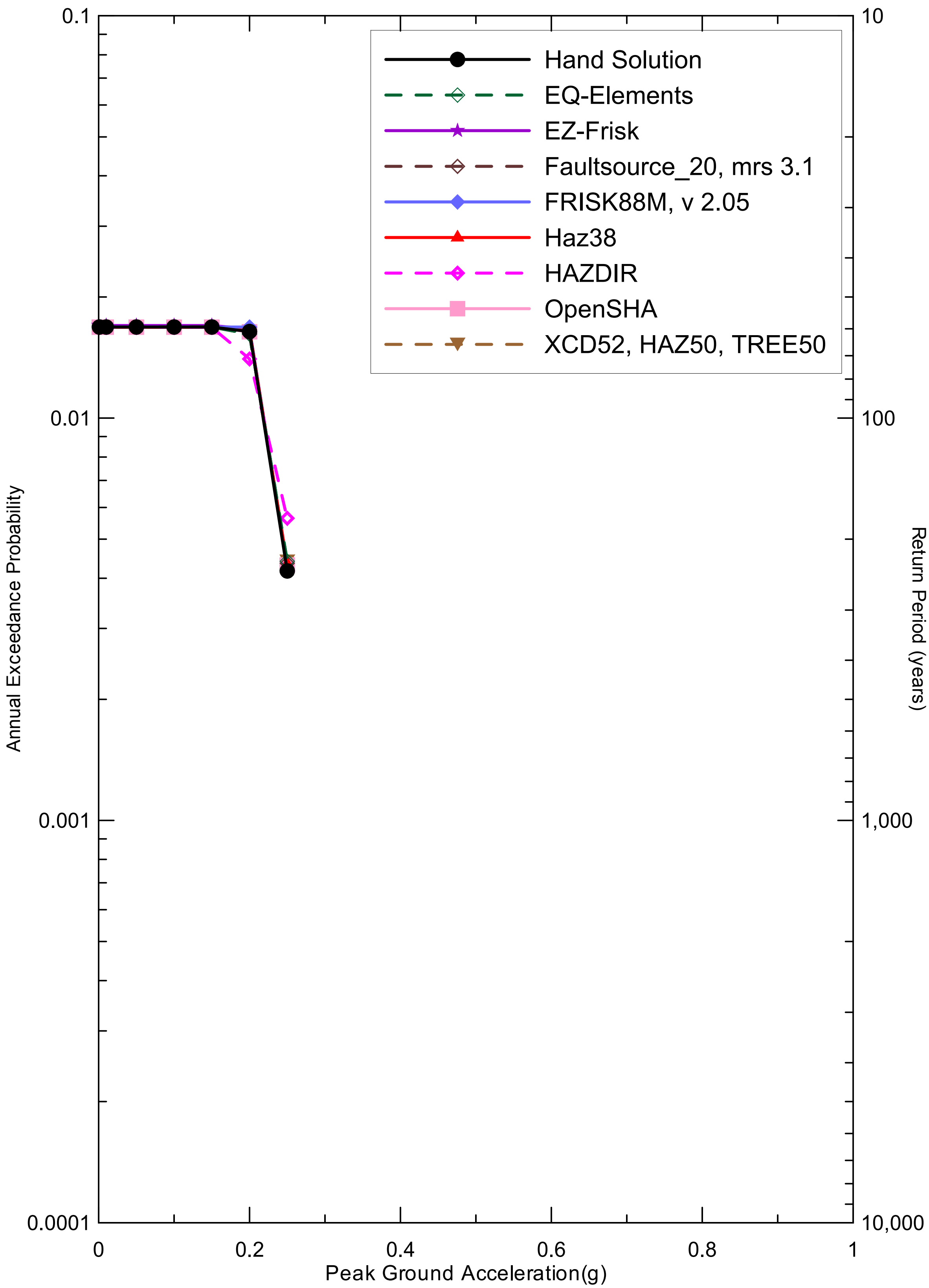
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 4	Figure 3.29



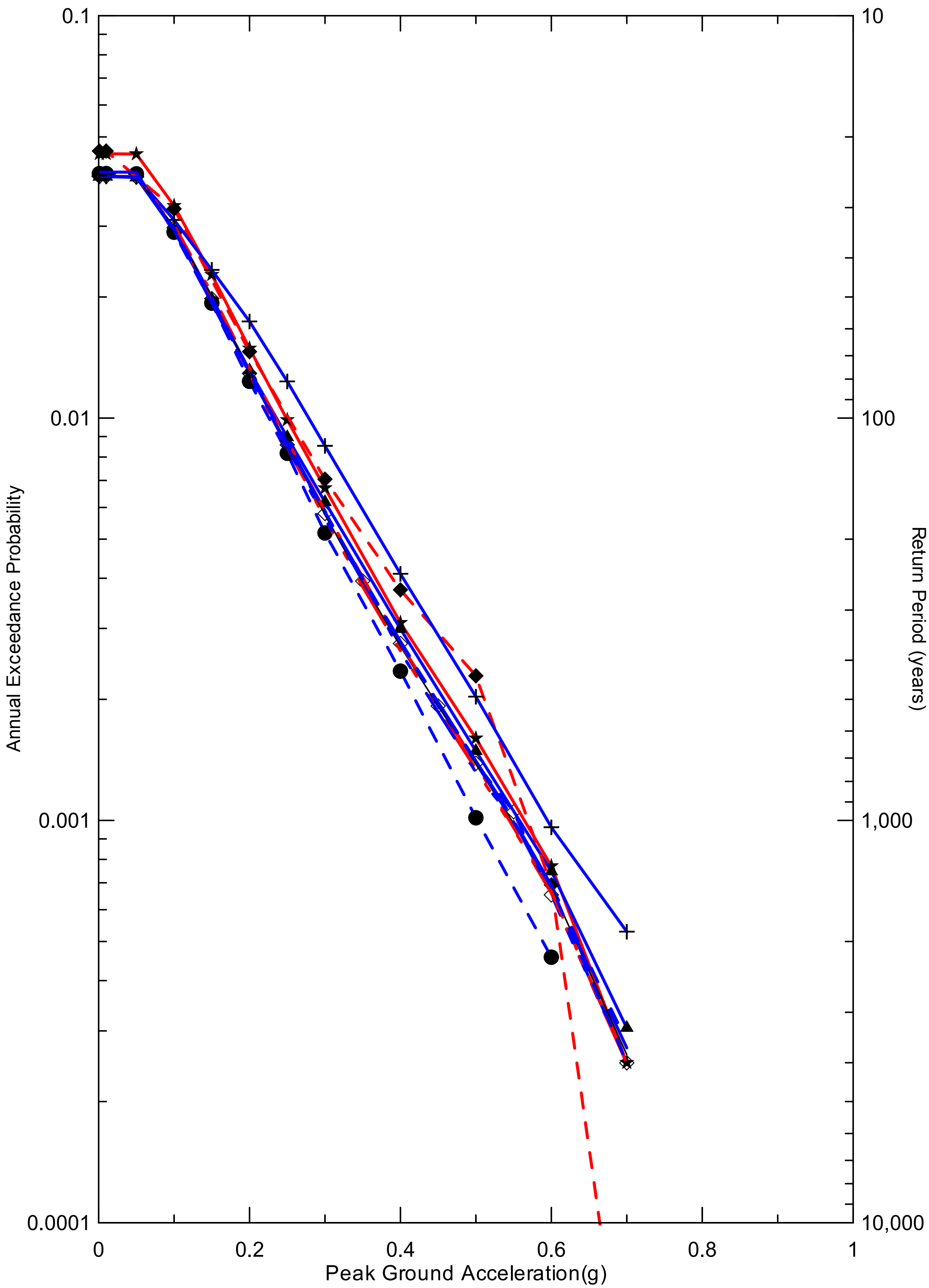
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 5	Figure 3.30



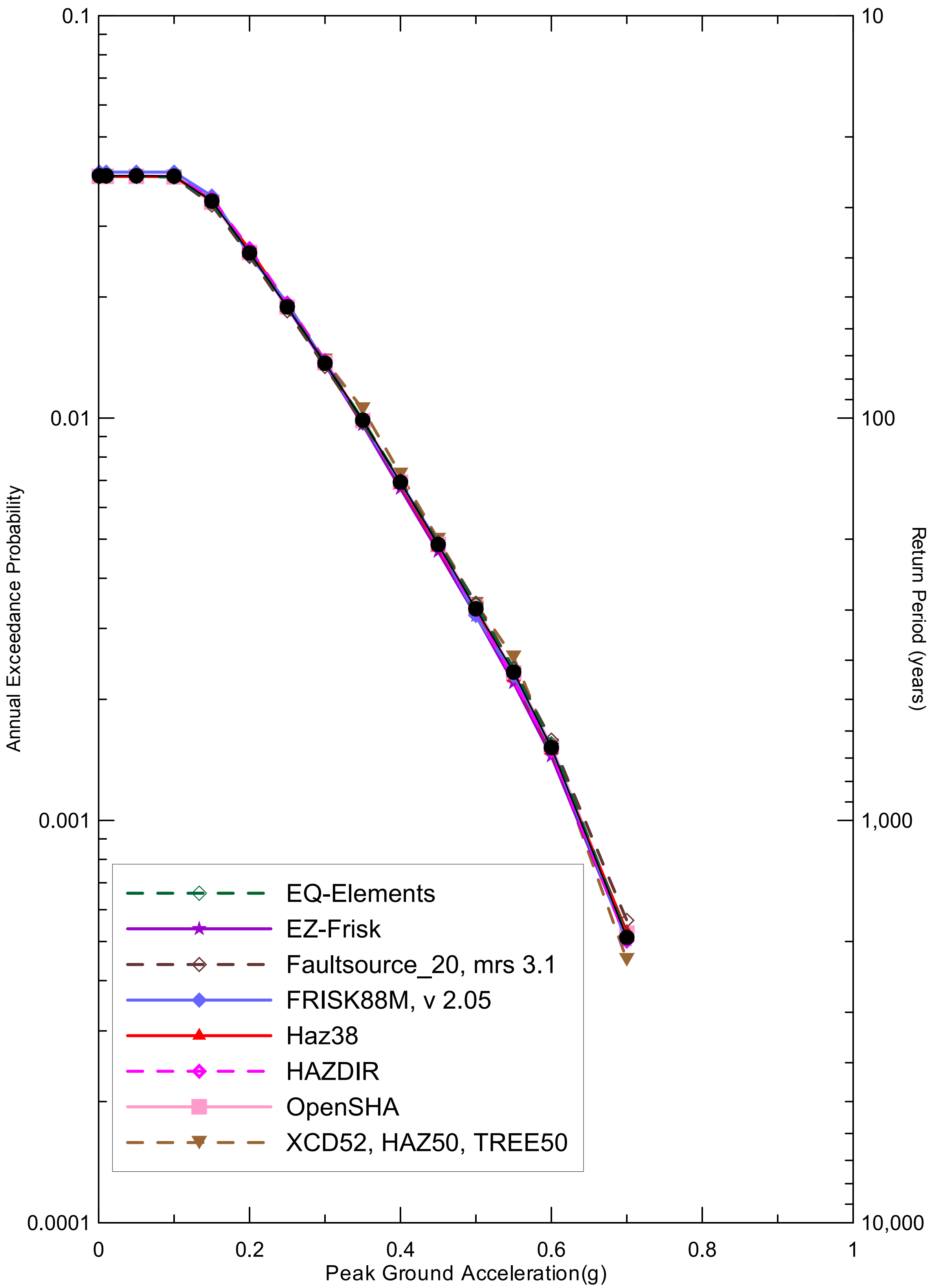
	PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 6	Figure 3.31



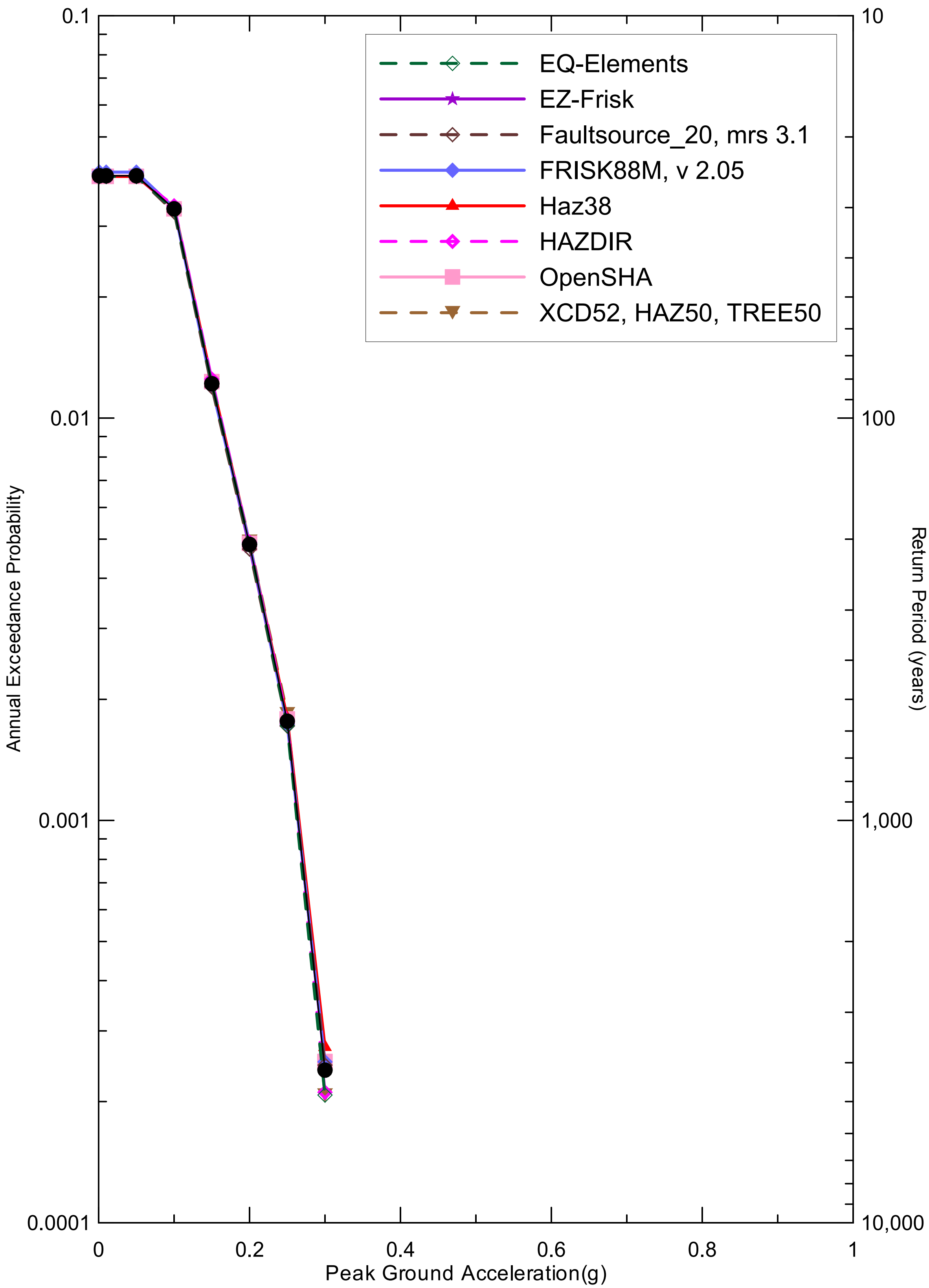
PEER PSHA VERIFICATION	TEST SET 1, CASE 4, SITE 7	Figure 3.32



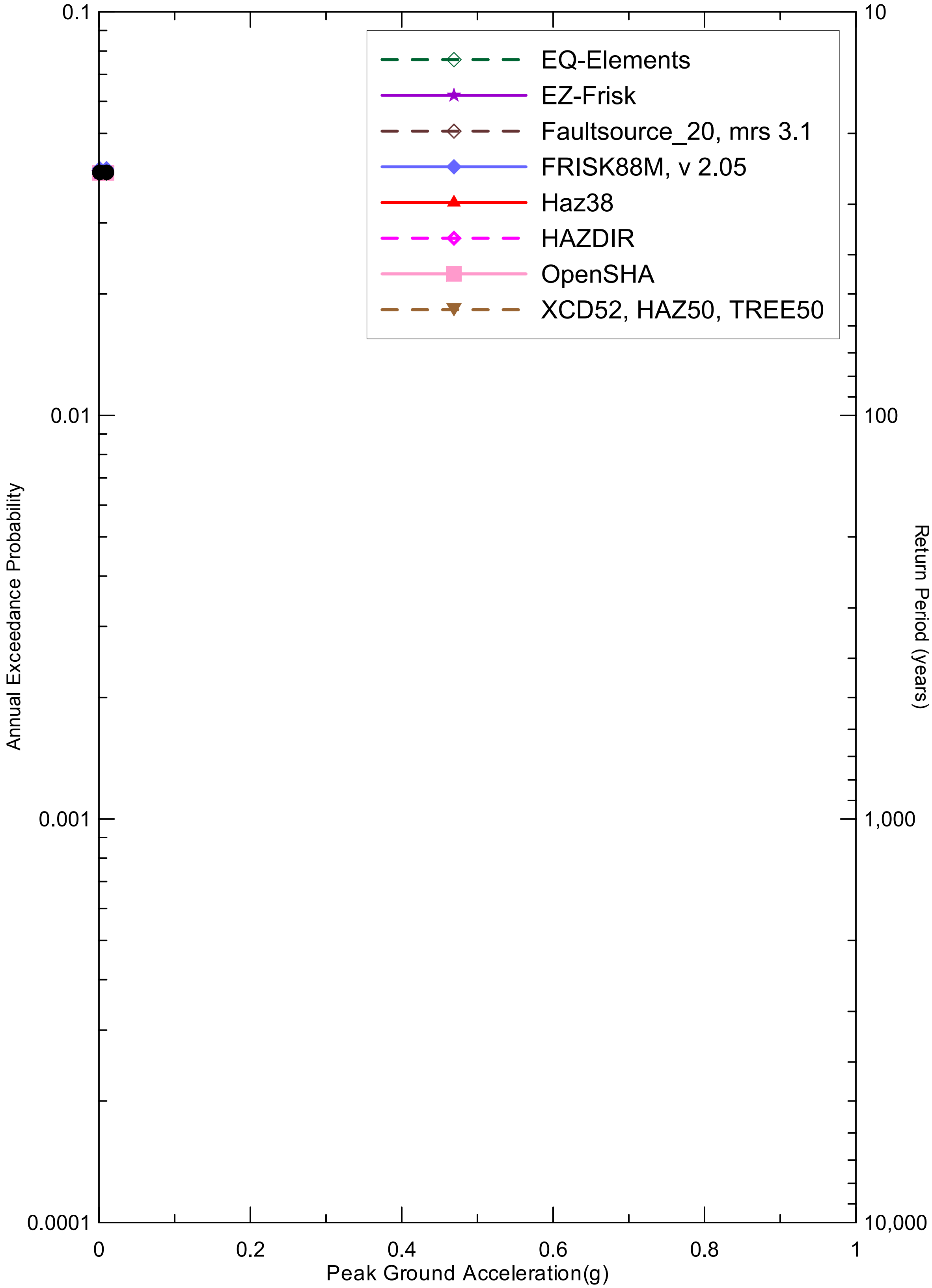
	PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 4 EARLY RESULTS	Figure 3.33



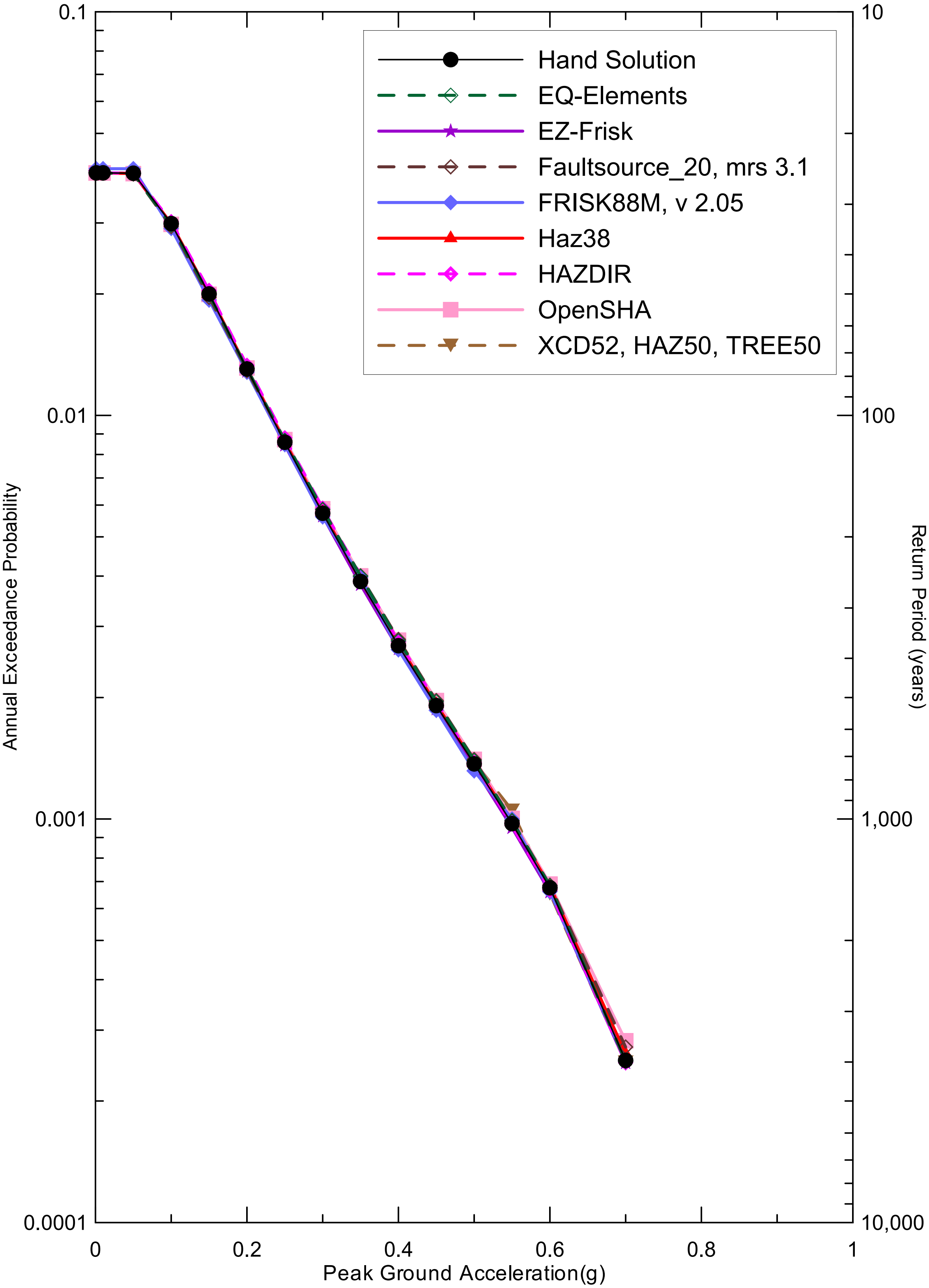
	PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 1	Figure 3.34



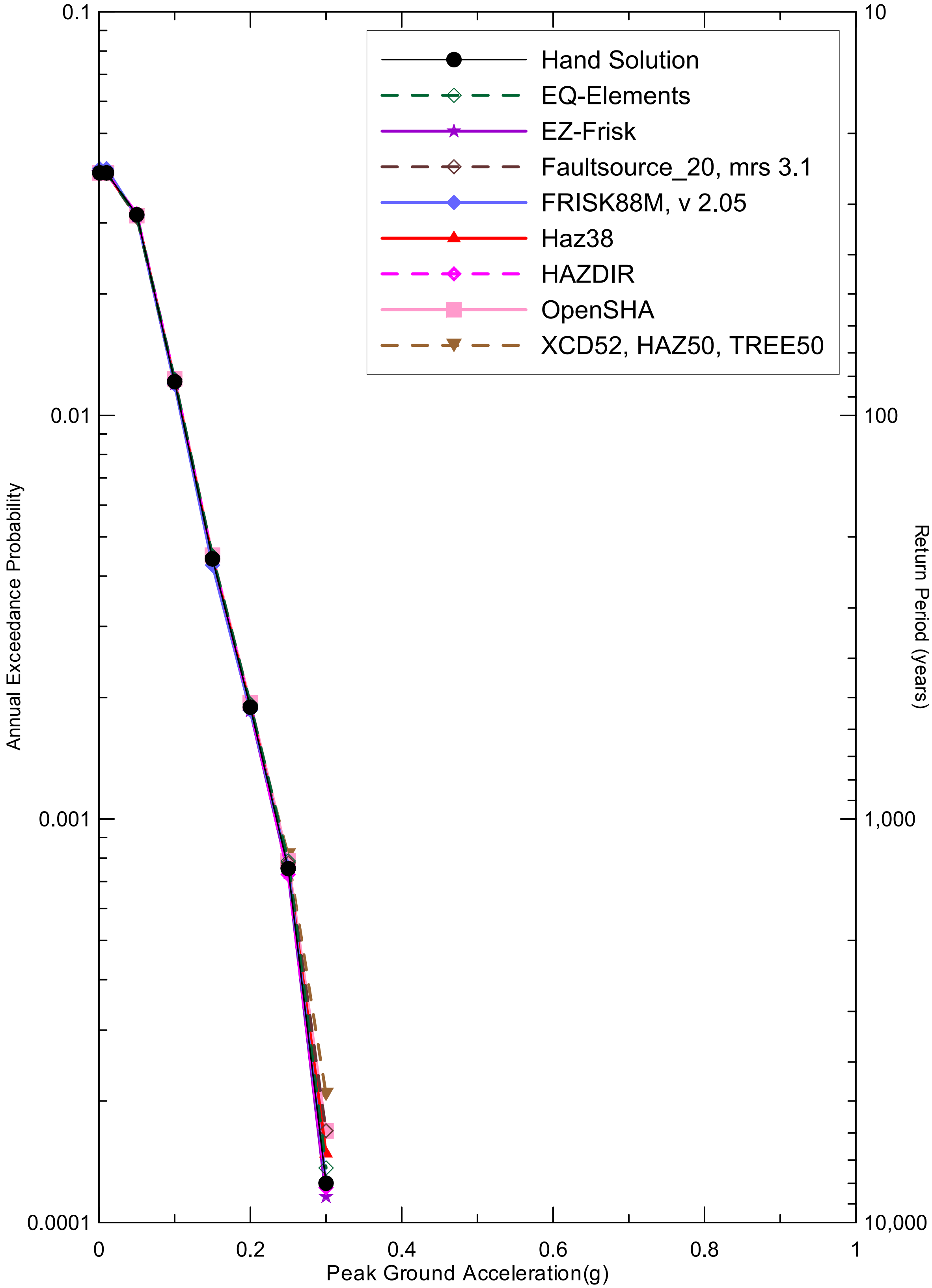
PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 2	Figure 3.35



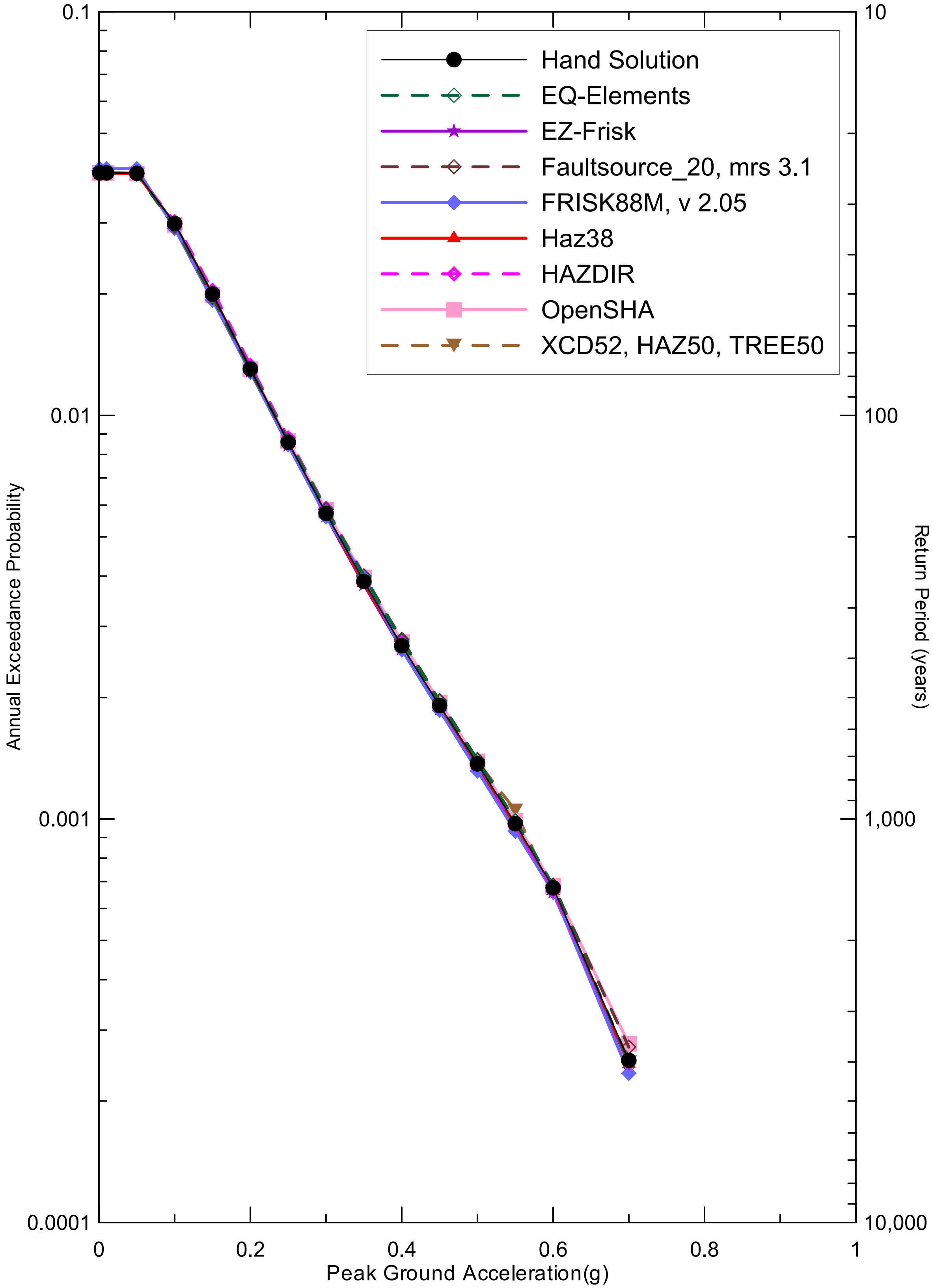
	PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 3	Figure 3.36



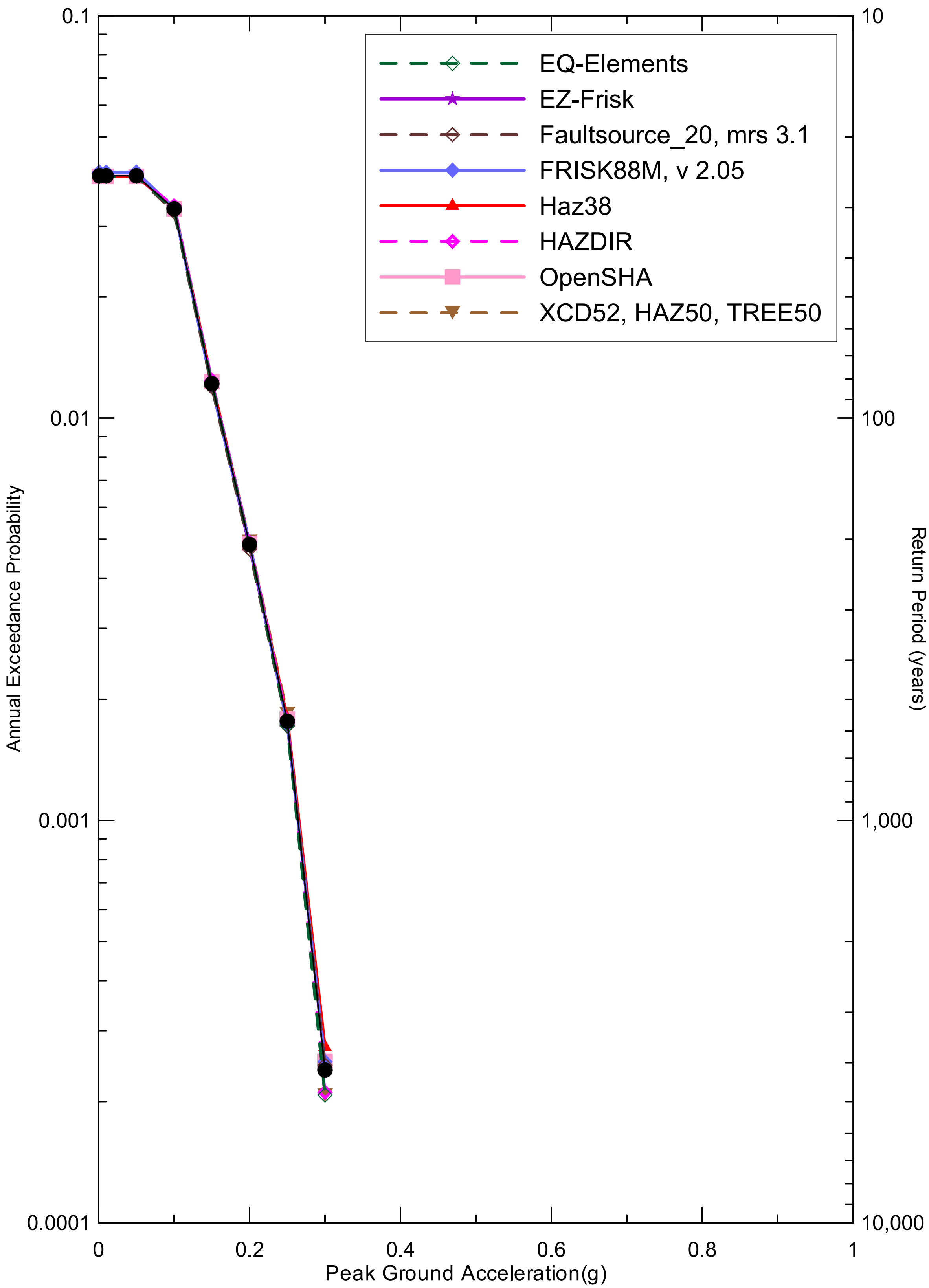
	PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 4	Figure 3.37



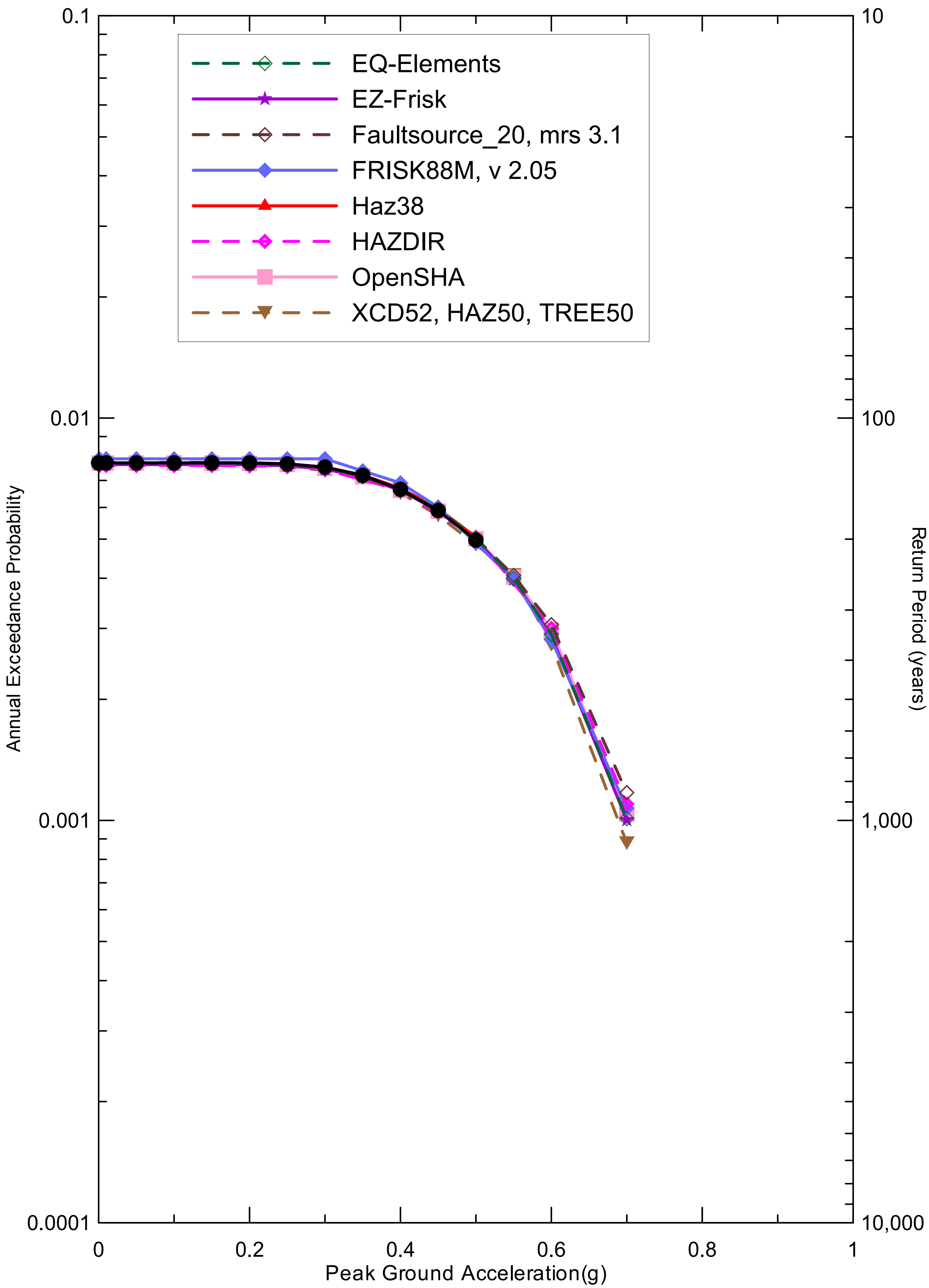
PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 5	Figure 3.38



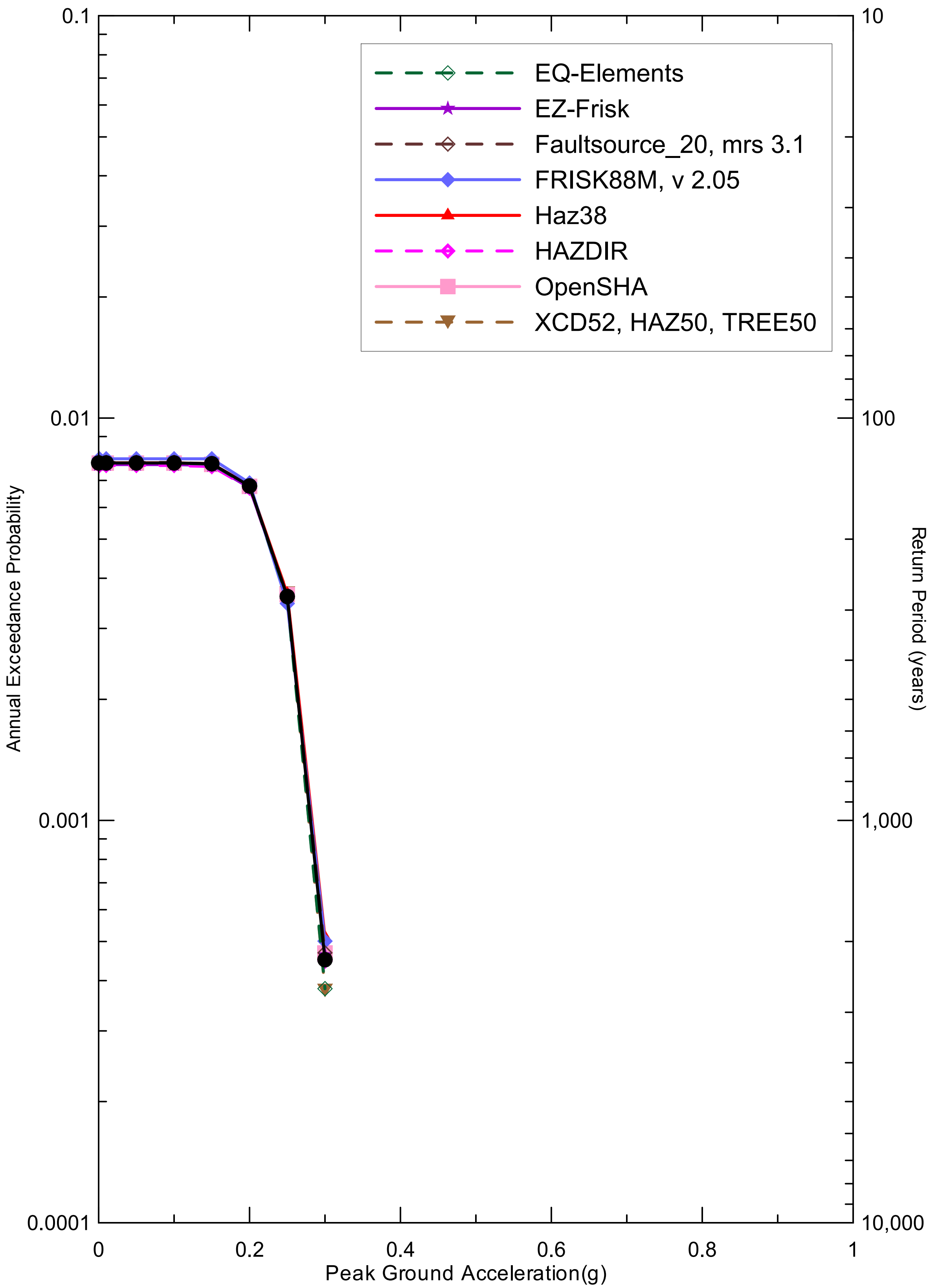
PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 6	Figure 3.39



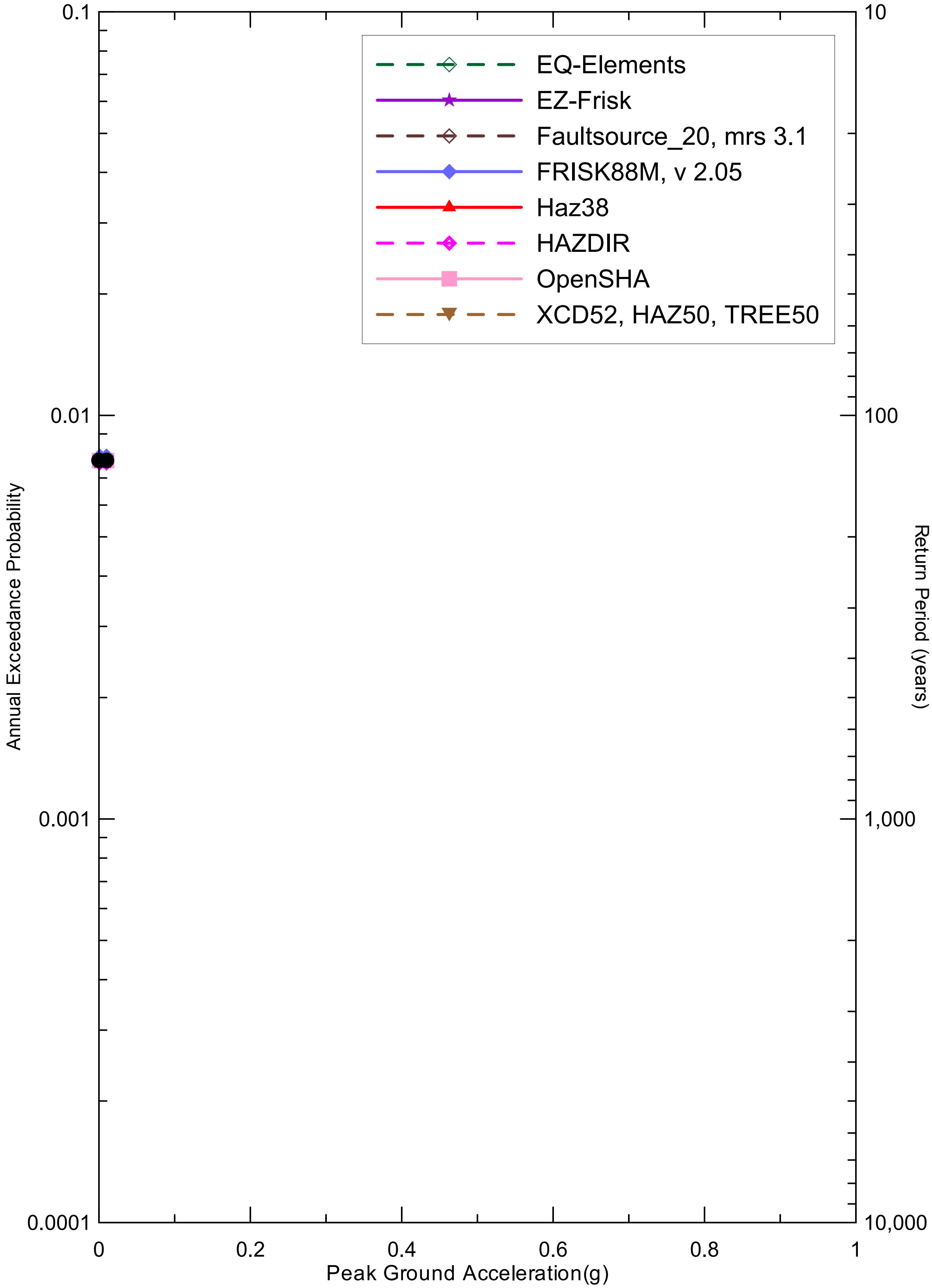
	PEER PSHA VERIFICATION	TEST SET 1, CASE 5, SITE 7	Figure 3.40



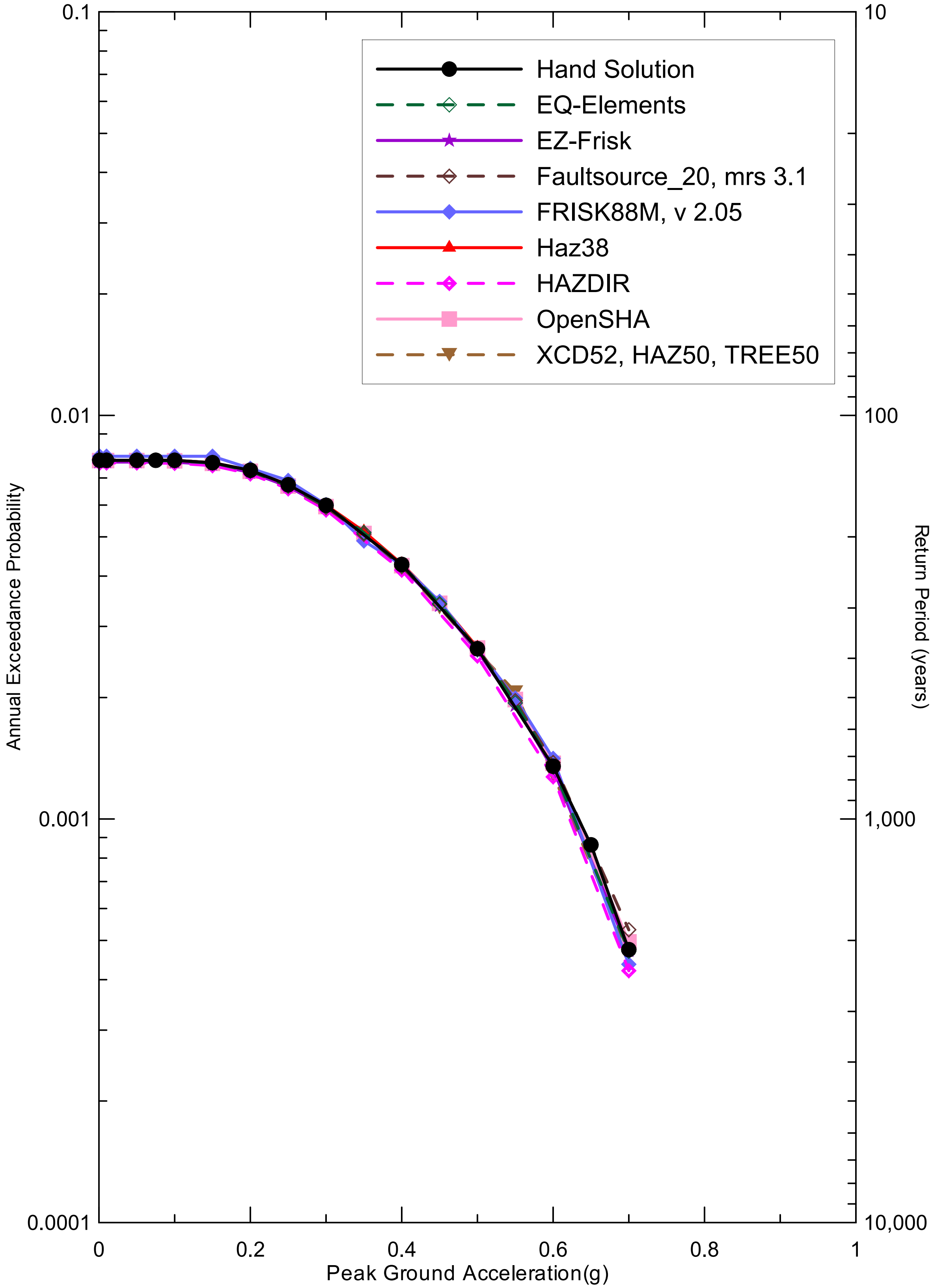
	PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 1	Figure 3.41



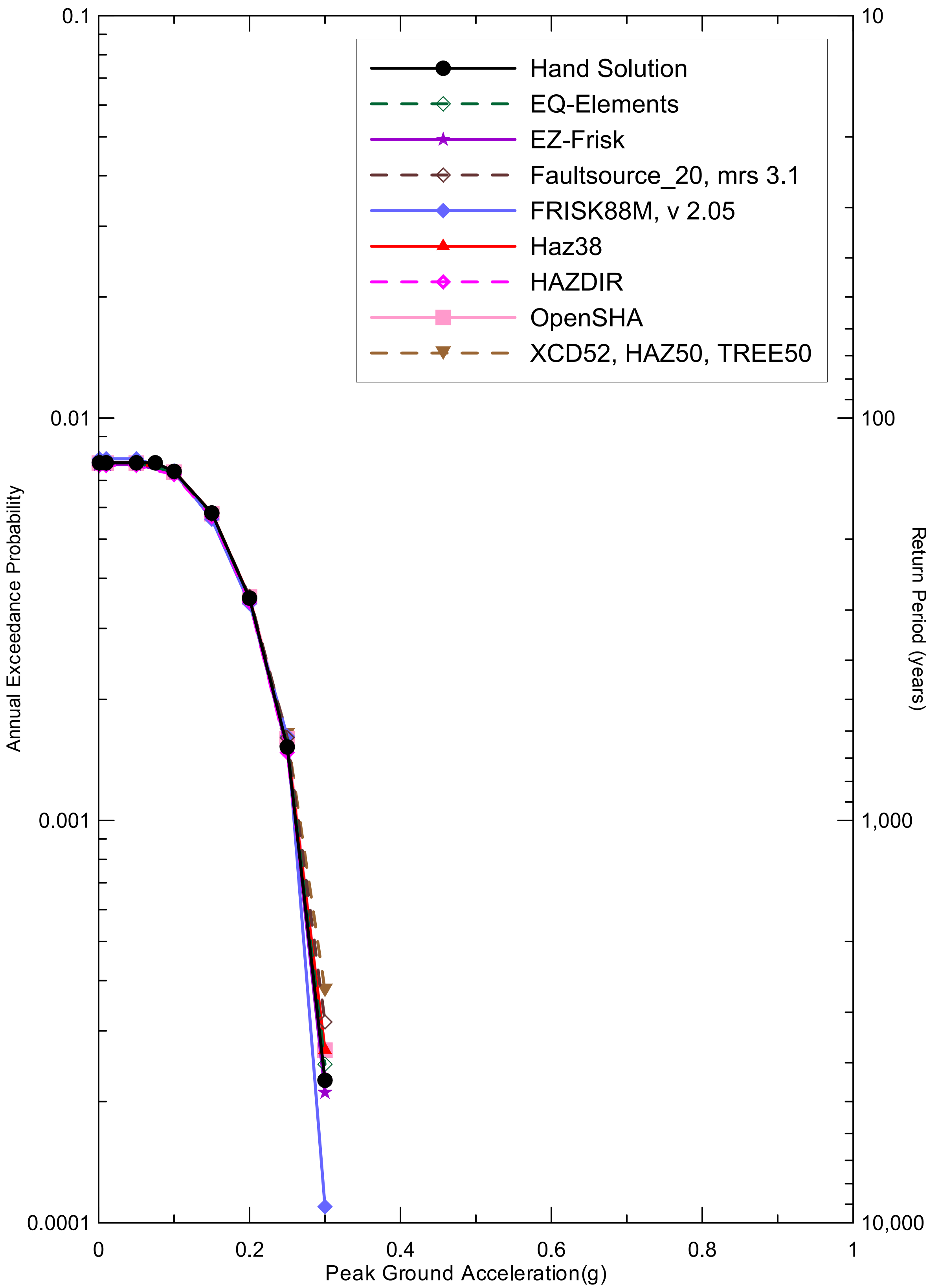
PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 2	Figure 3.42



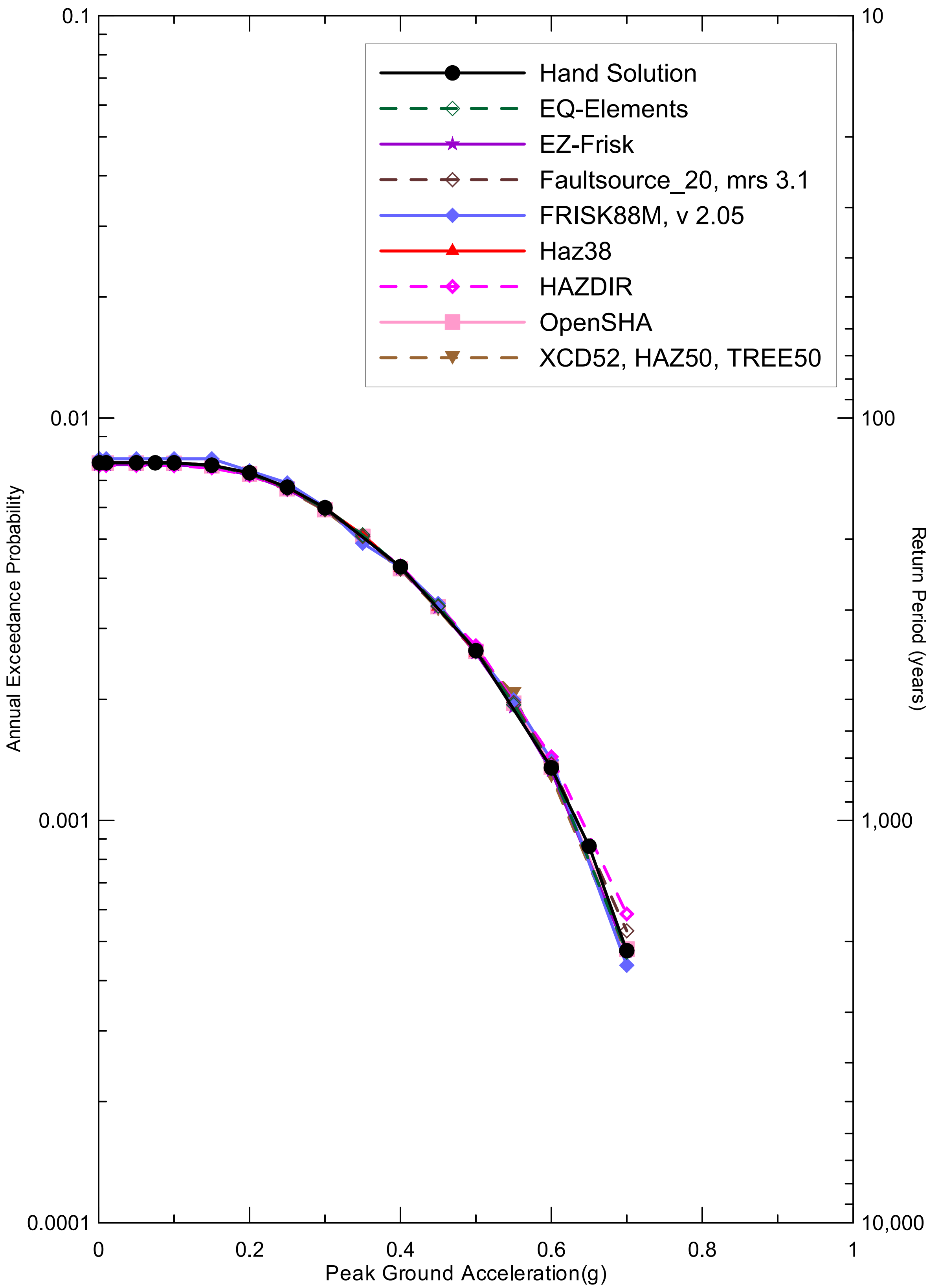
	PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 3	Figure 3.43



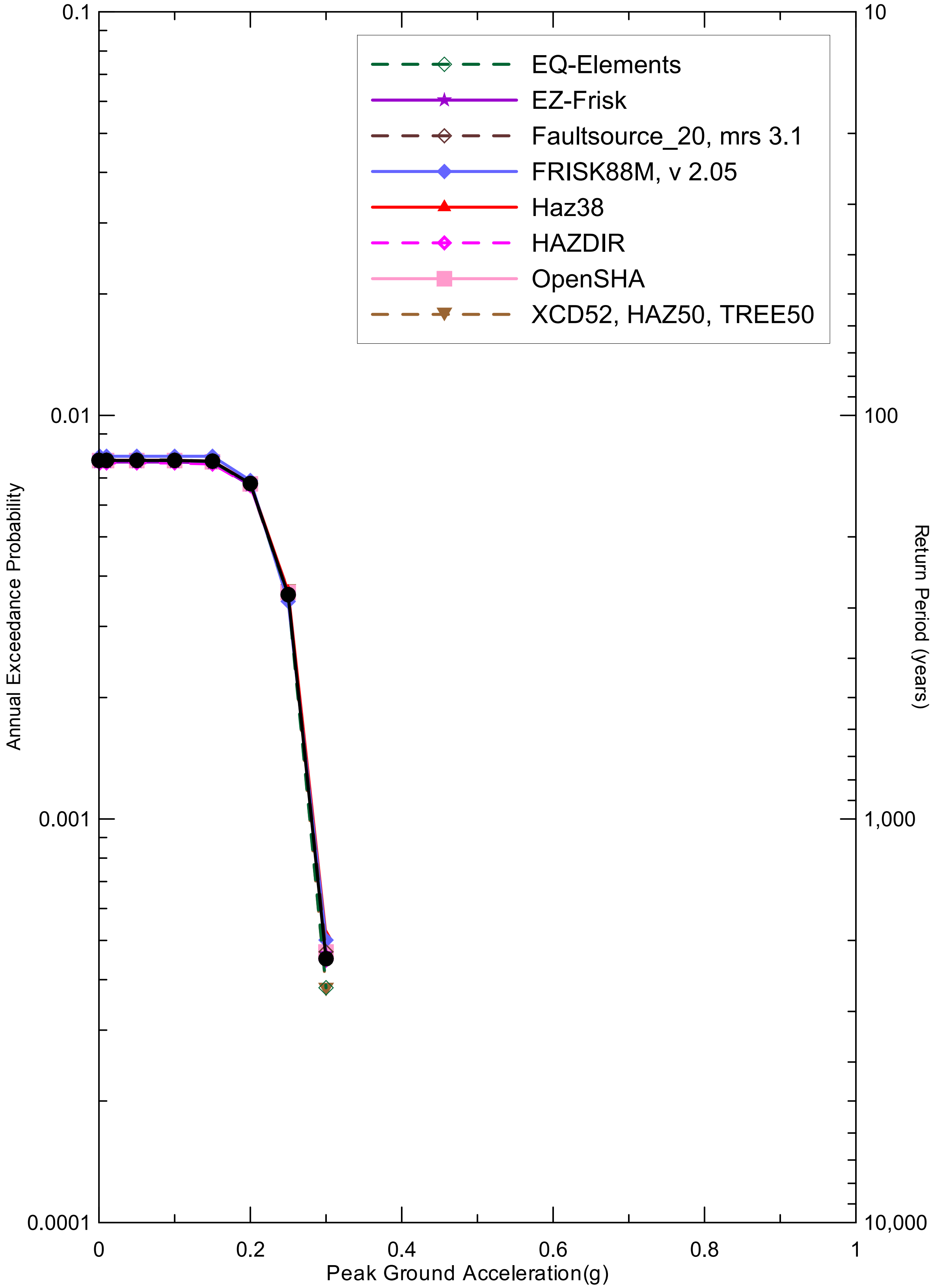
PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 4	Figure 3.44



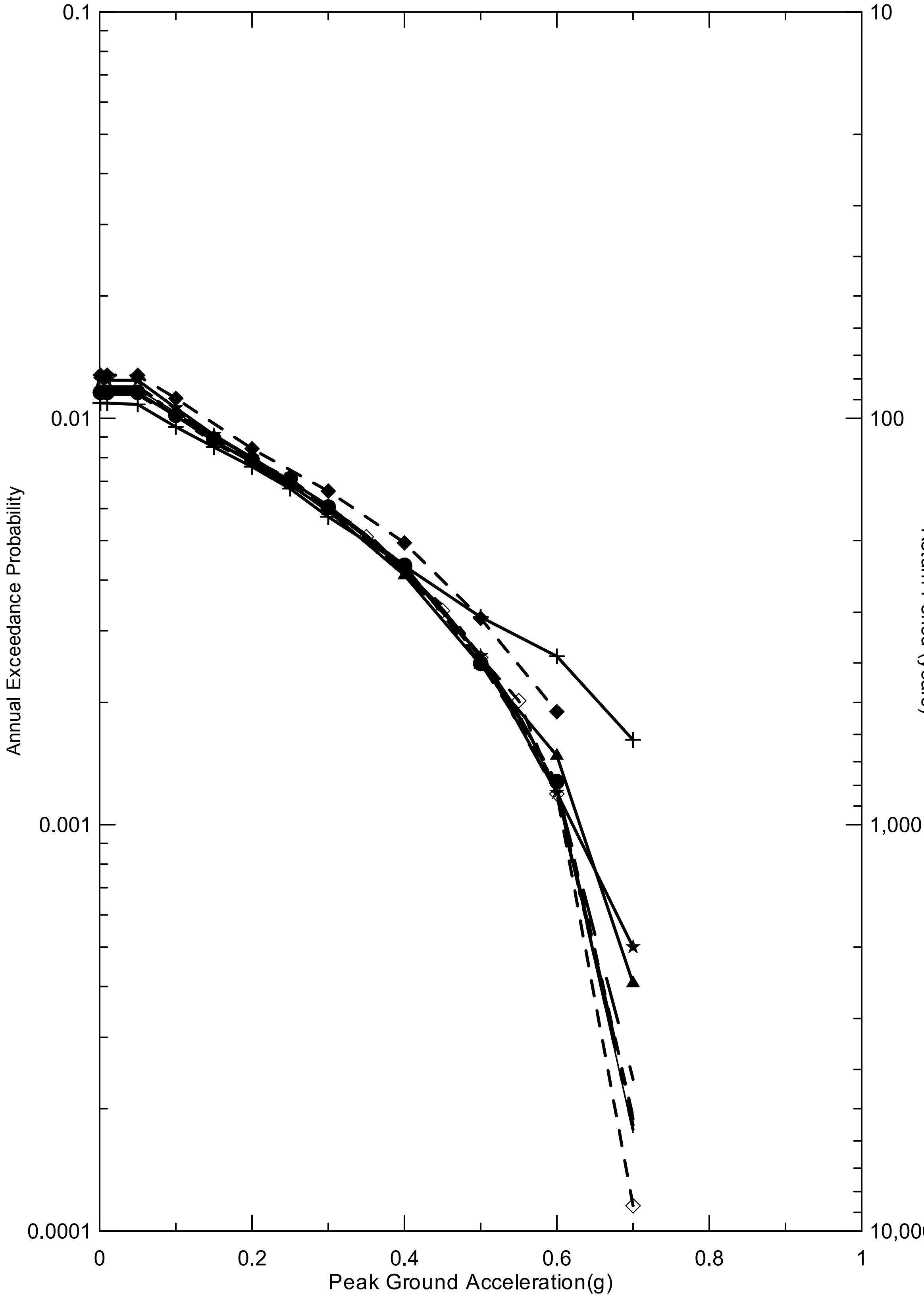
PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 5	Figure 3.45



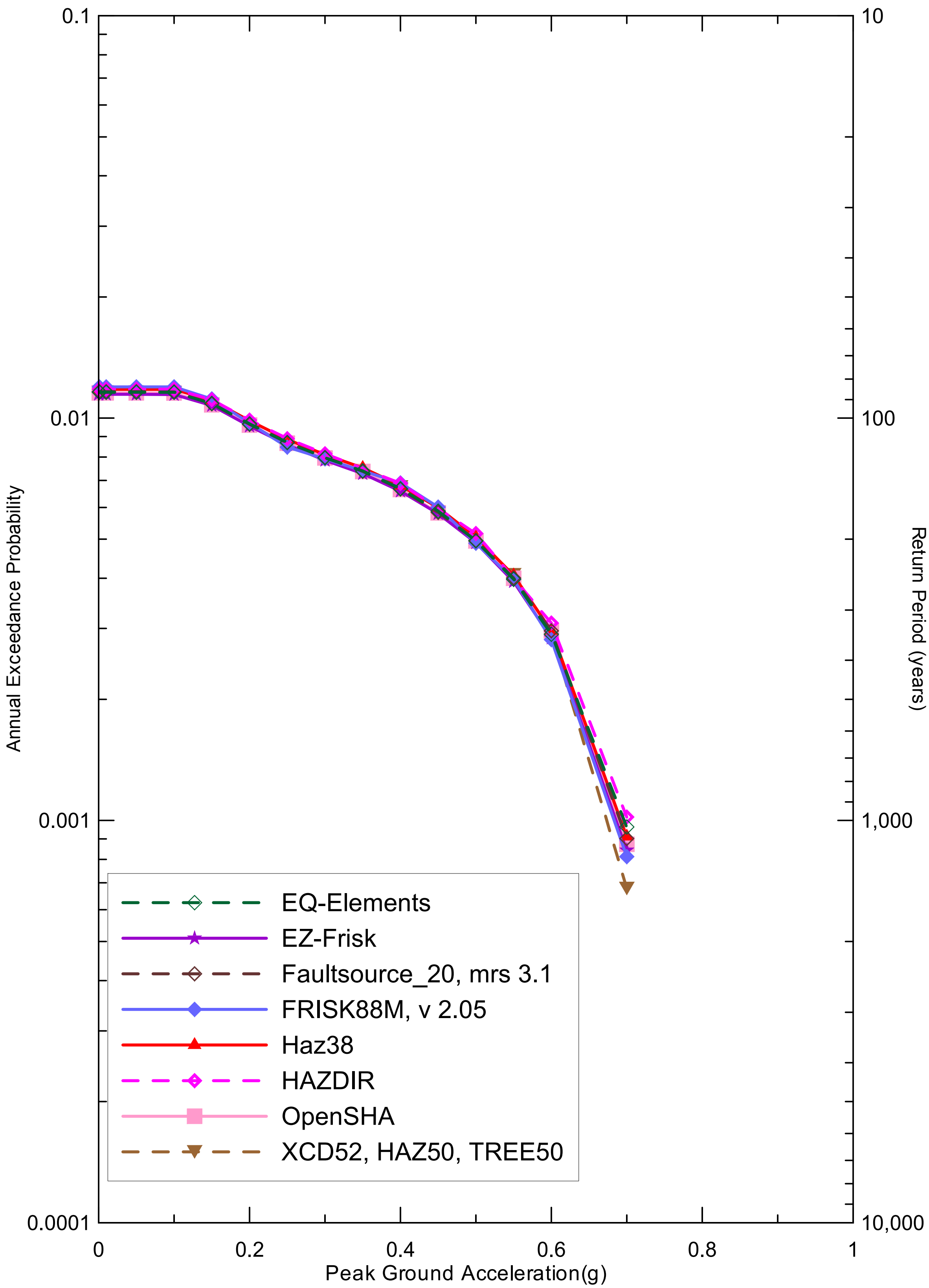
PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 6	Figure 3.46



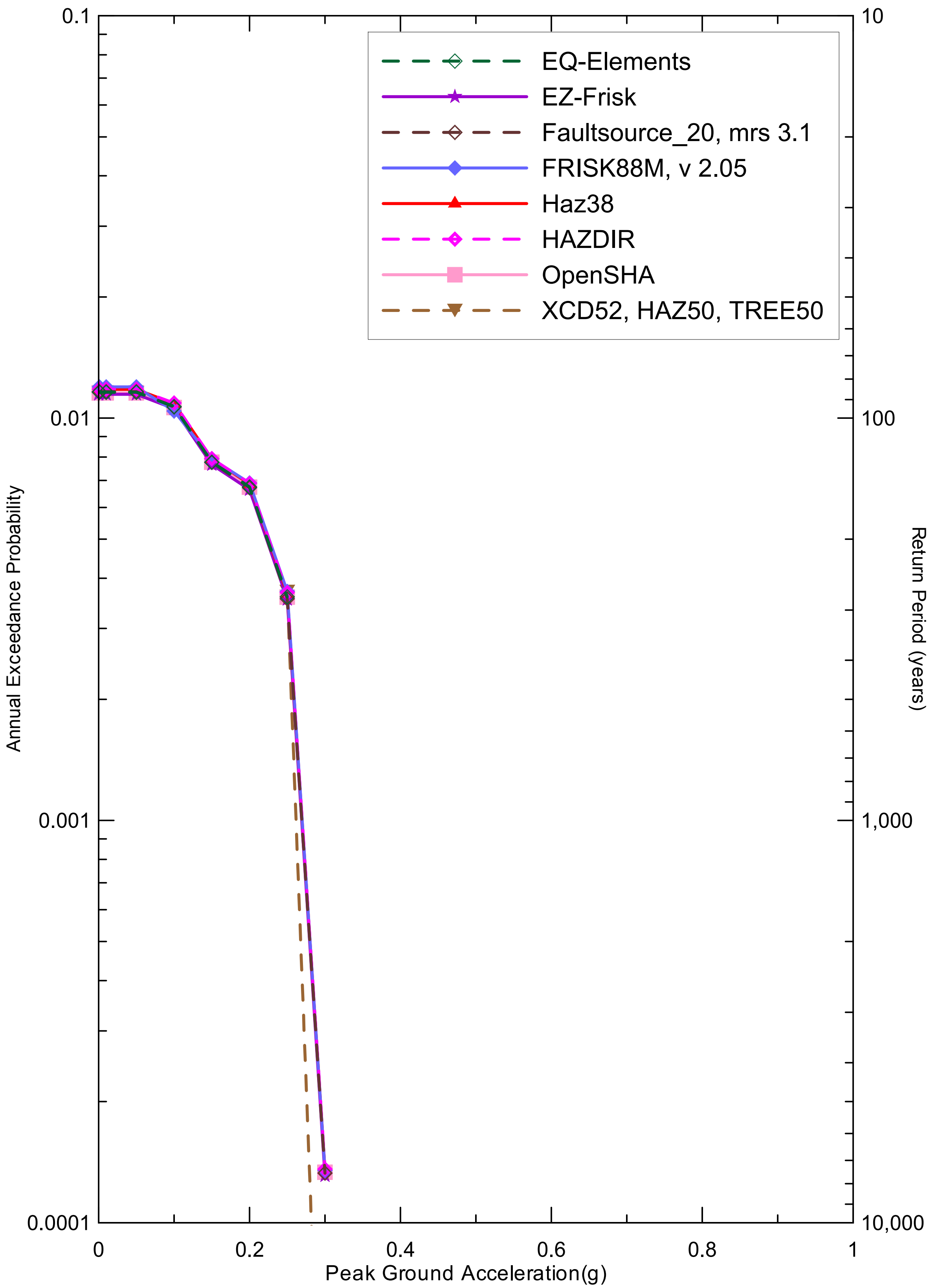
	PEER PSHA VERIFICATION	TEST SET 1, CASE 6, SITE 7	Figure 3.47



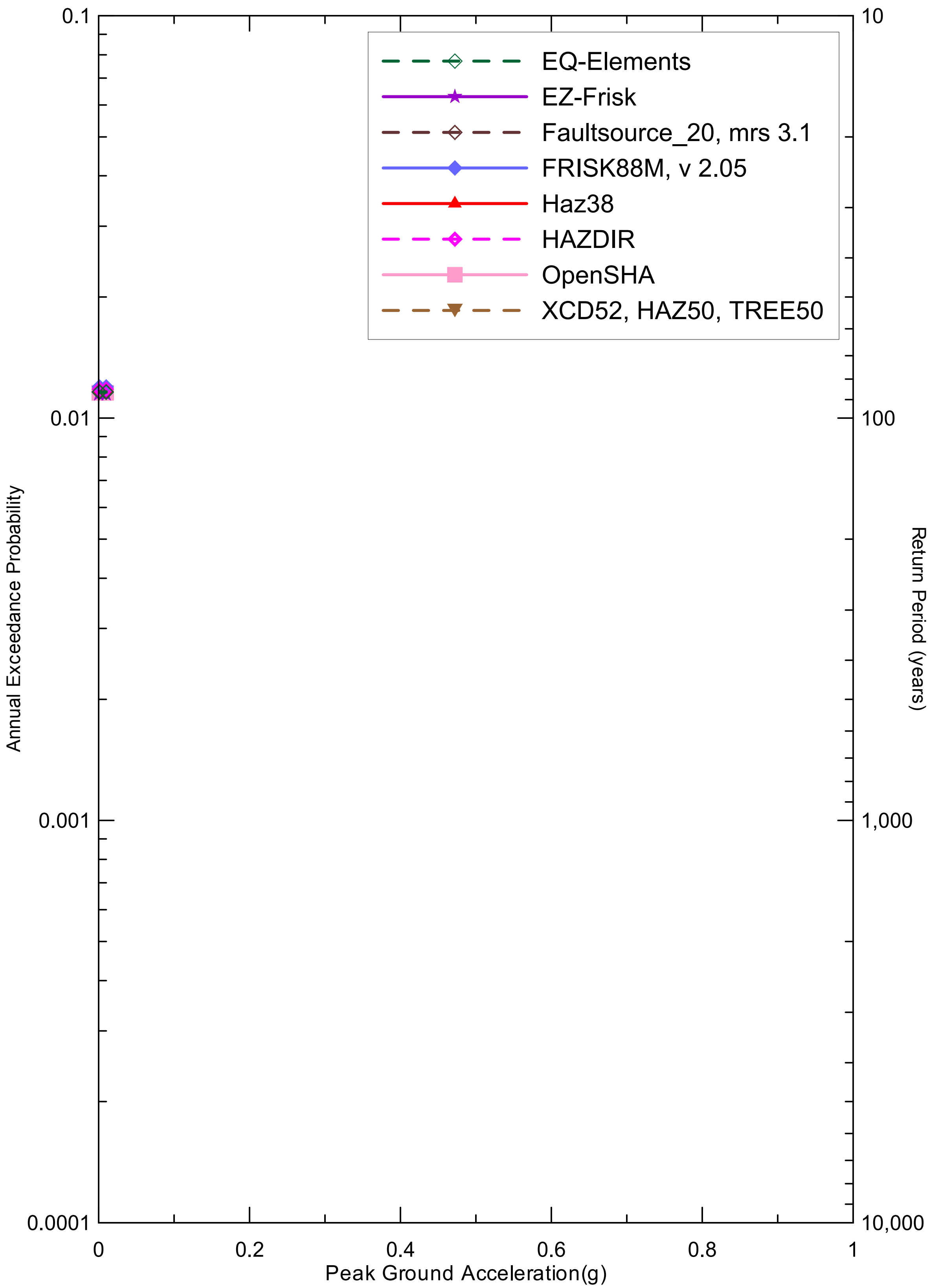
	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 6 EARLY RESULTS	Figure 3.48



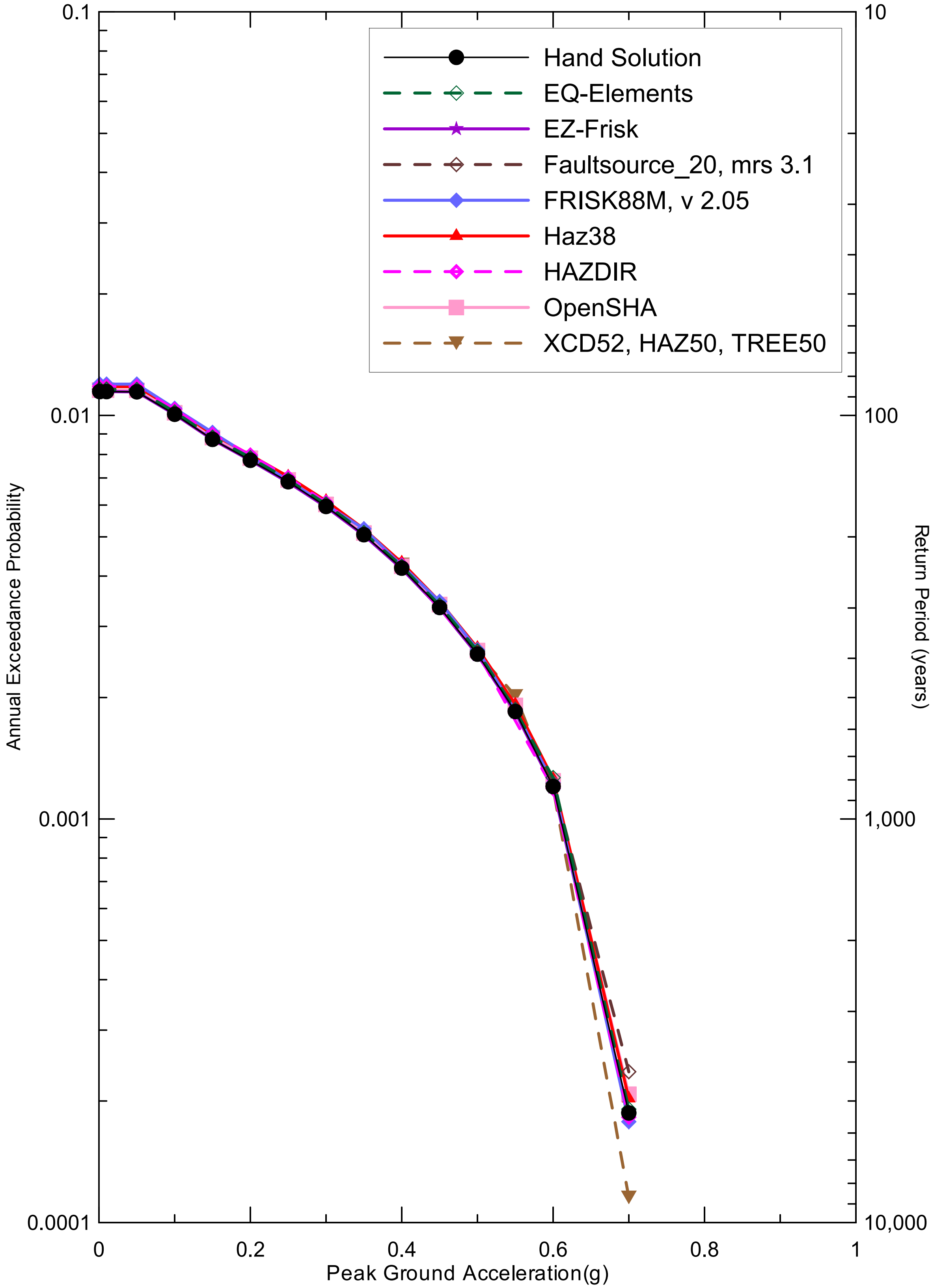
	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 1	Figure 3.49



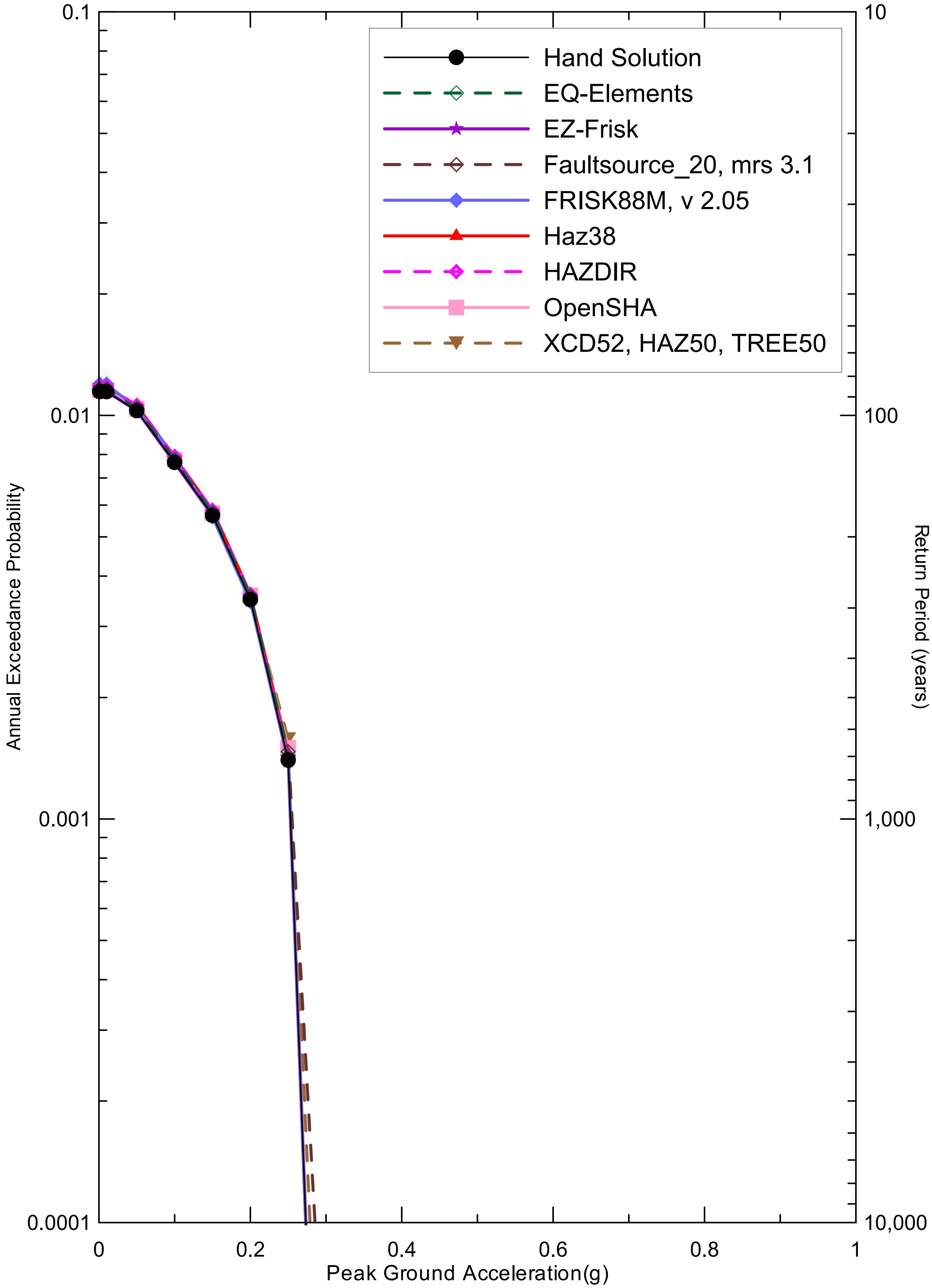
	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 2	Figure 3.50



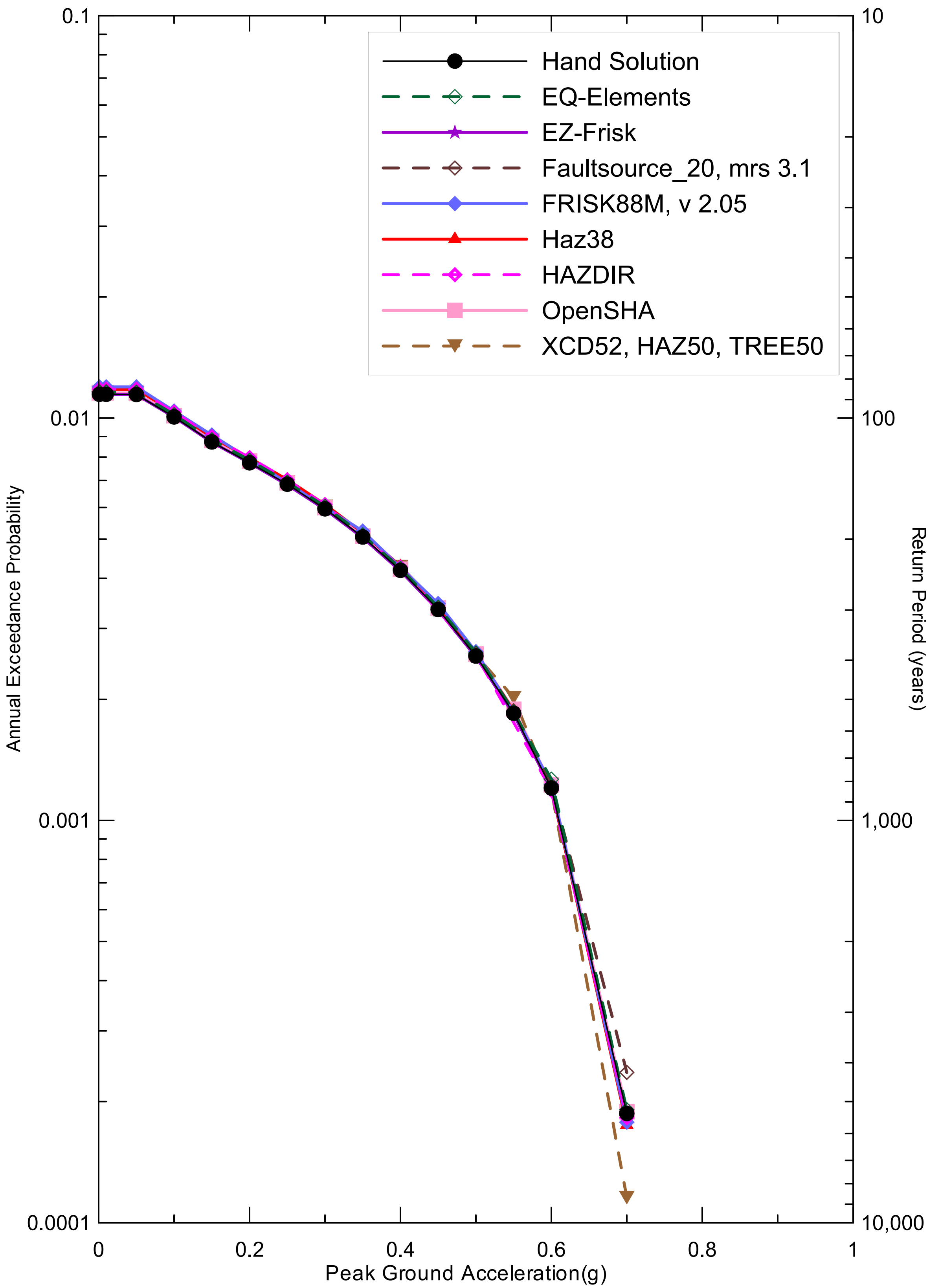
	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 3	Figure 3.51



	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 4	Figure 3.52



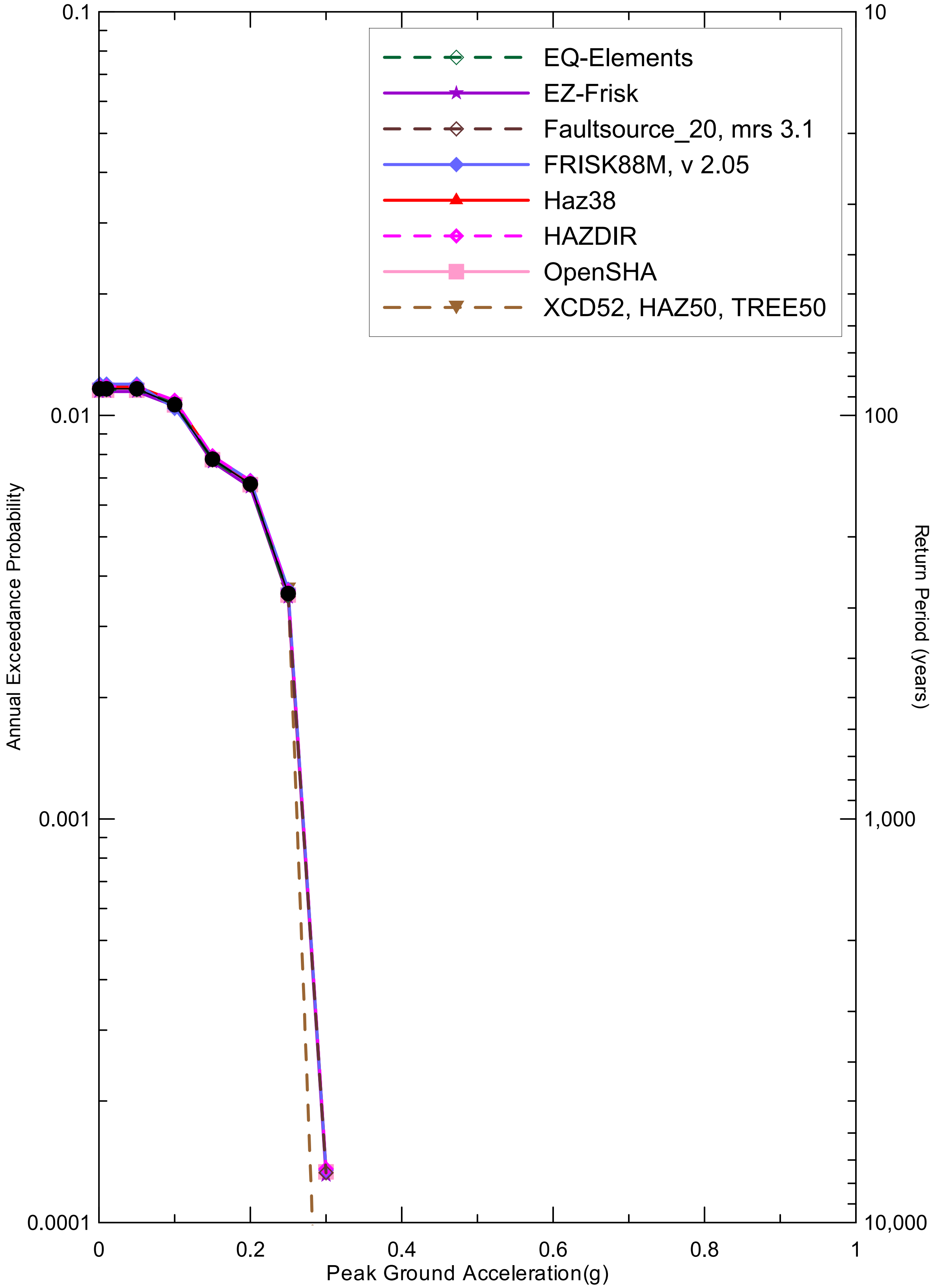
PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 5	Figure 3.53



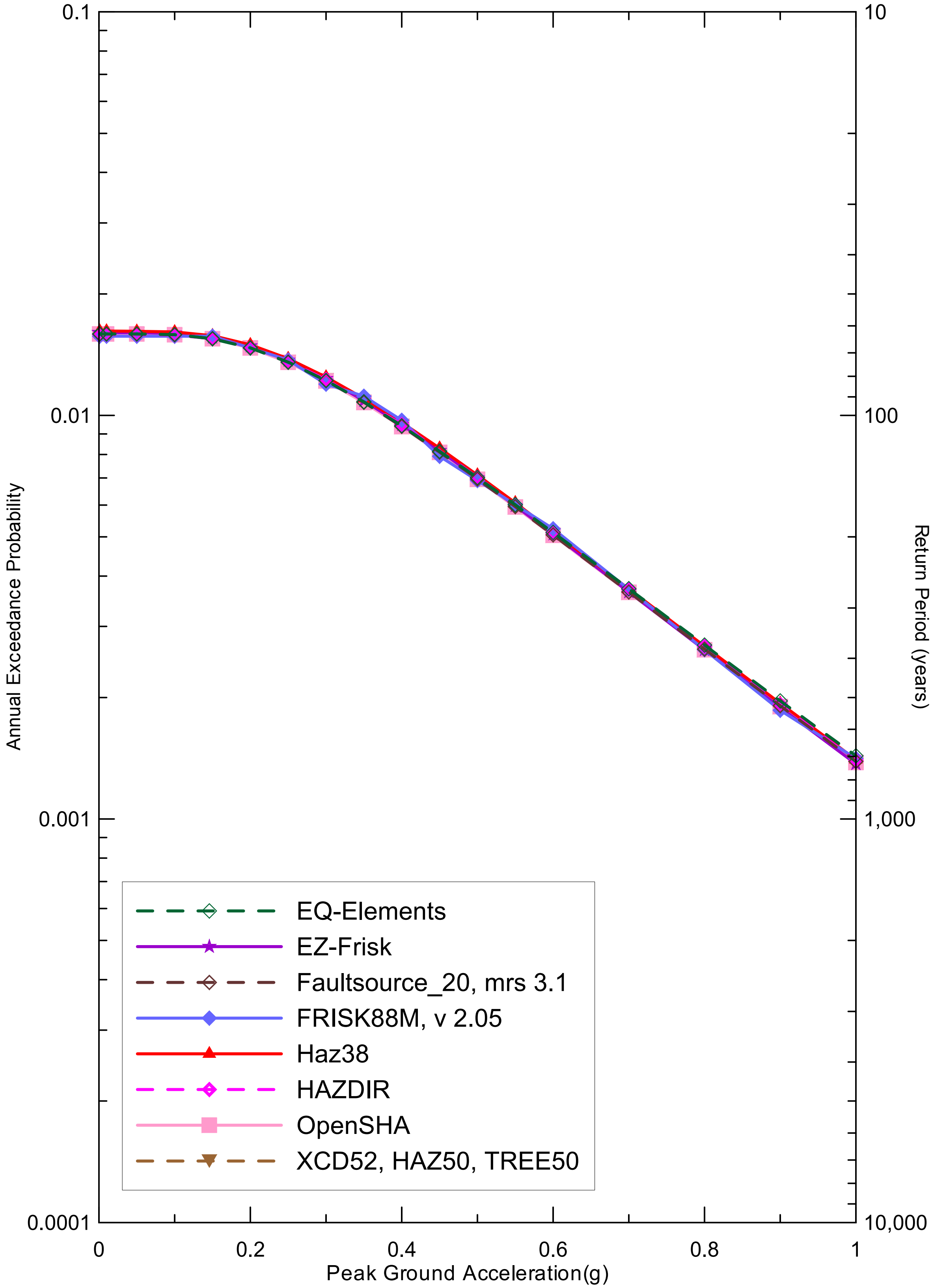
PEER PSHA VERIFICATION

TEST SET 1, CASE 7, SITE 6

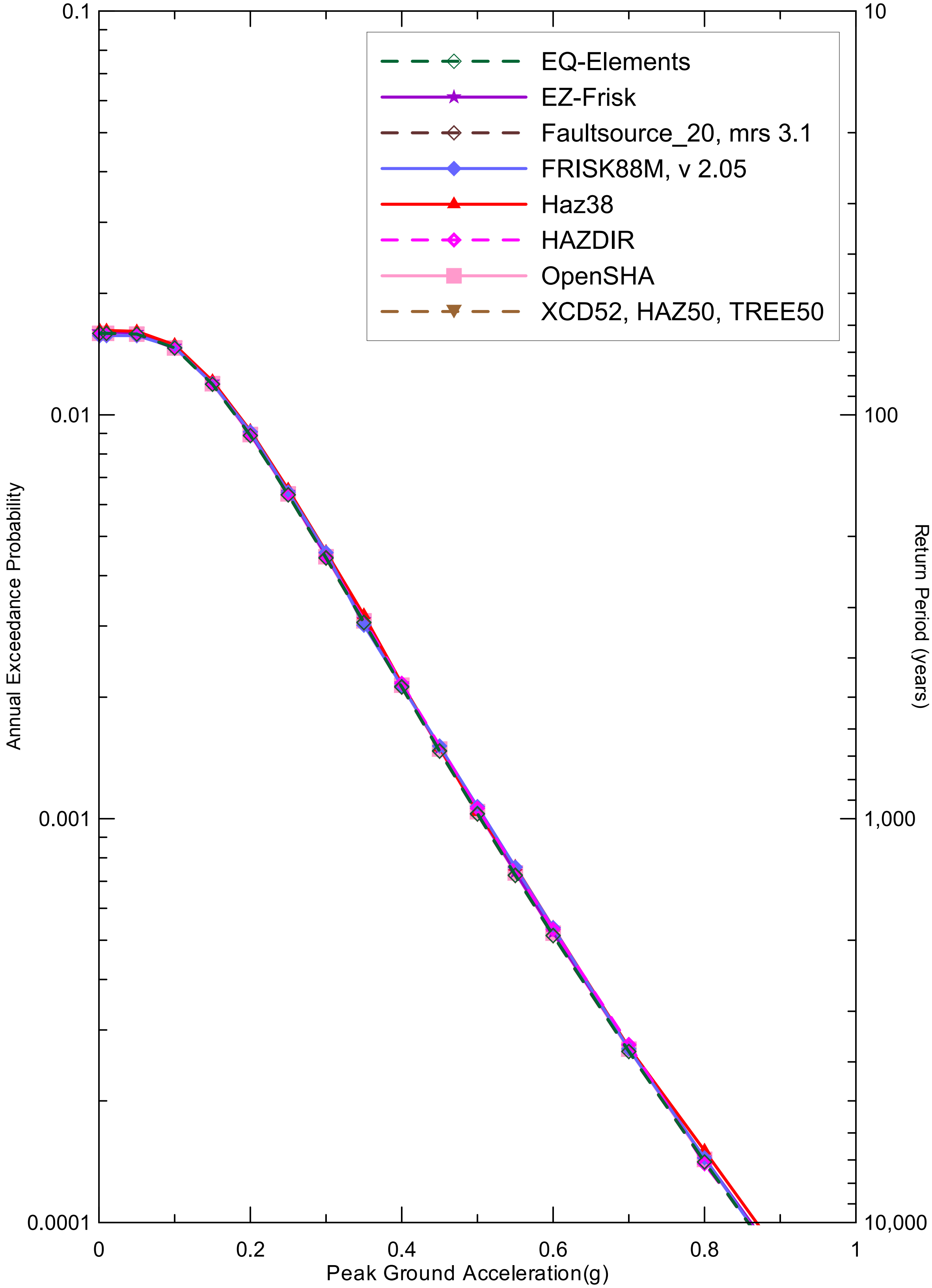
Figure 3.54



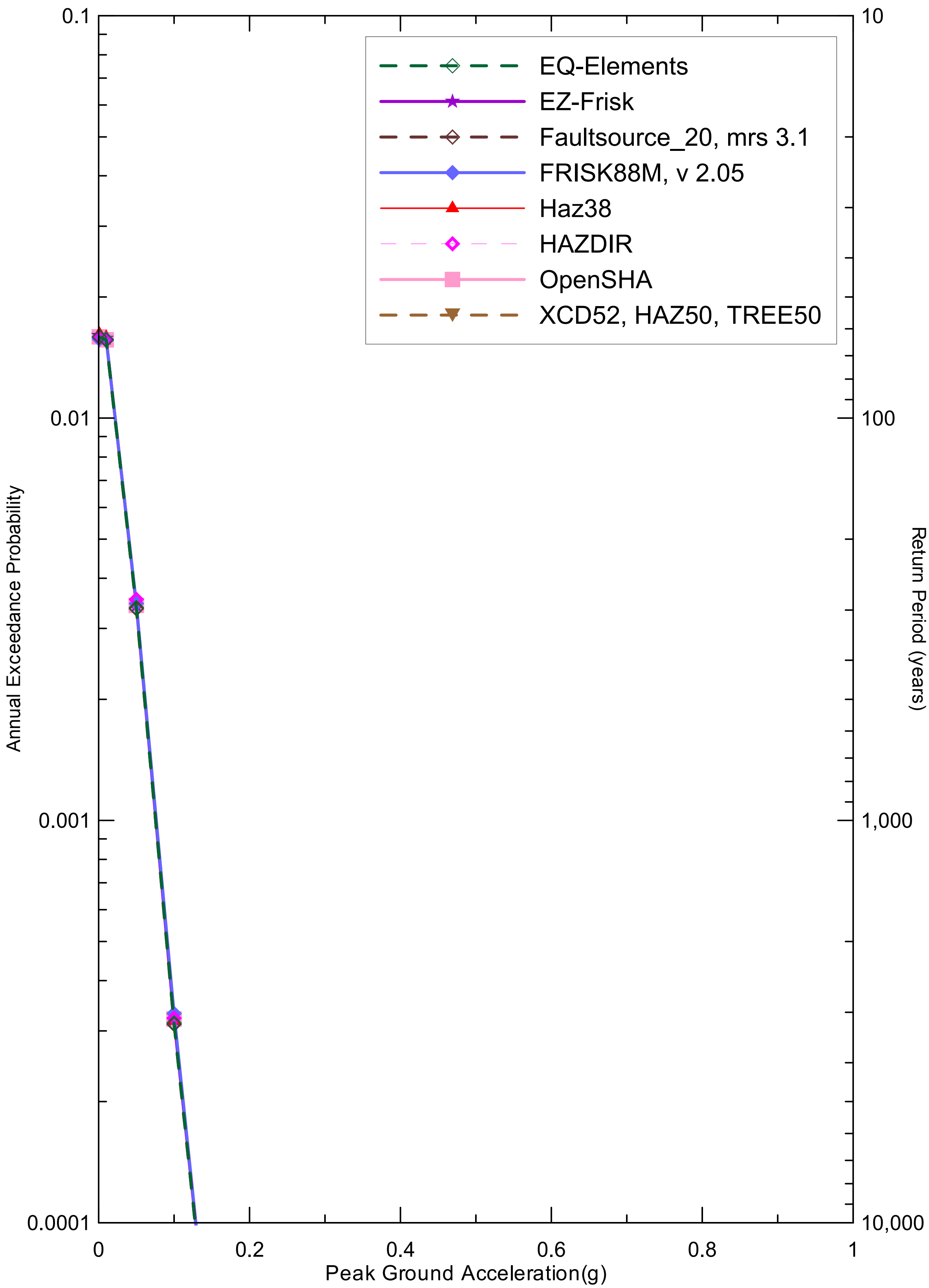
	PEER PSHA VERIFICATION	TEST SET 1, CASE 7, SITE 7	Figure 3.55



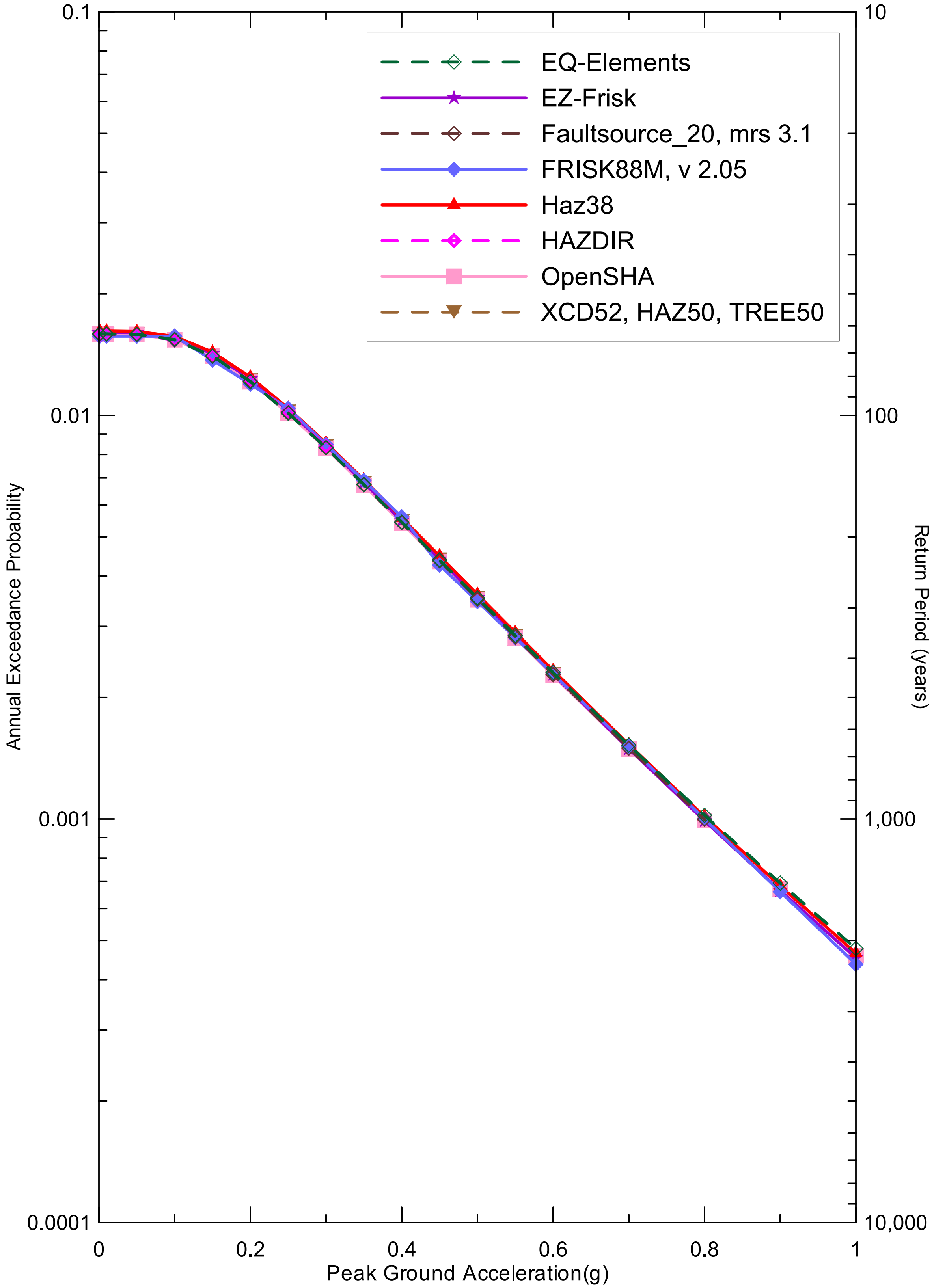
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 1	Figure 3.56



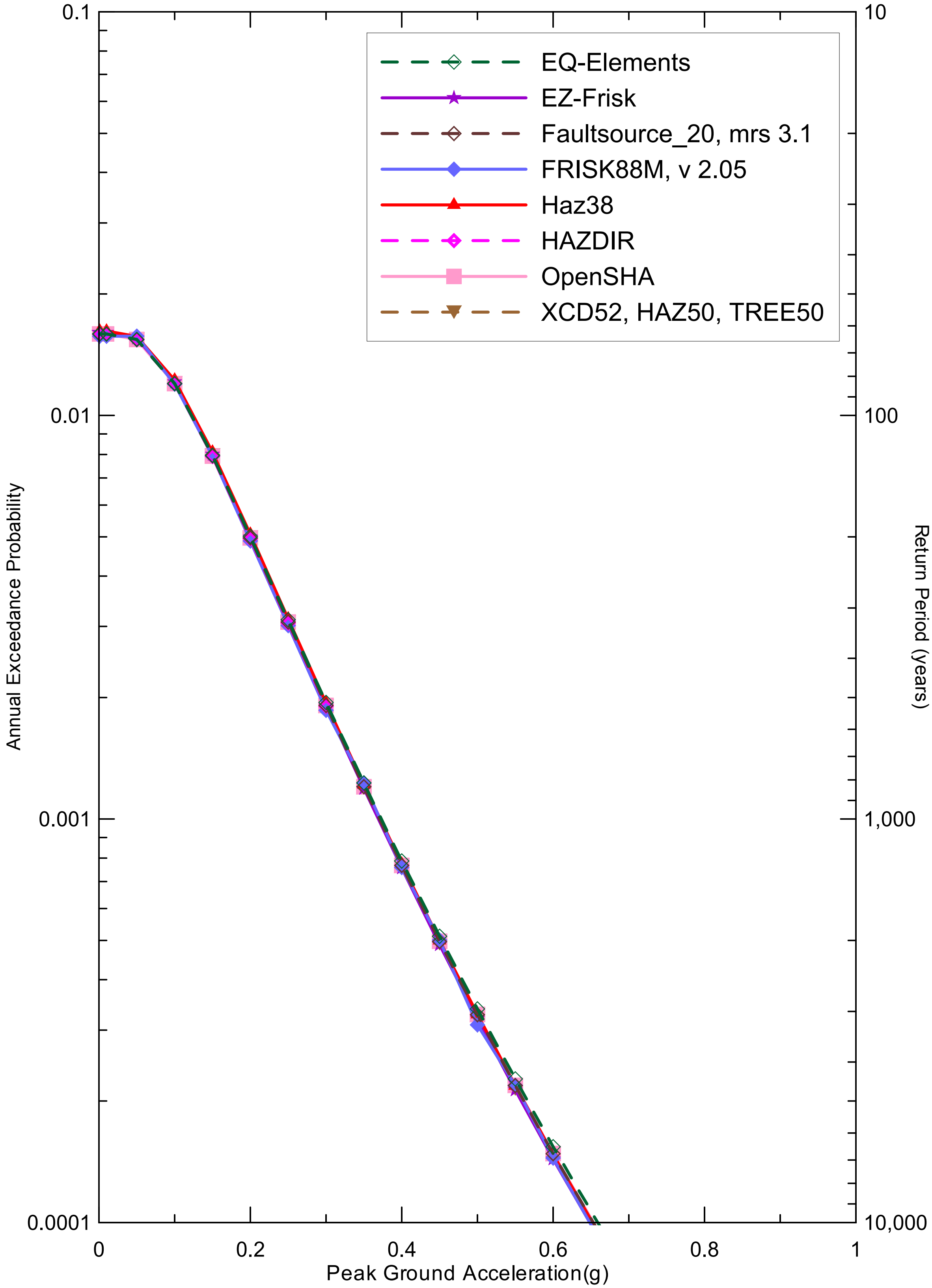
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 2	Figure 3.57



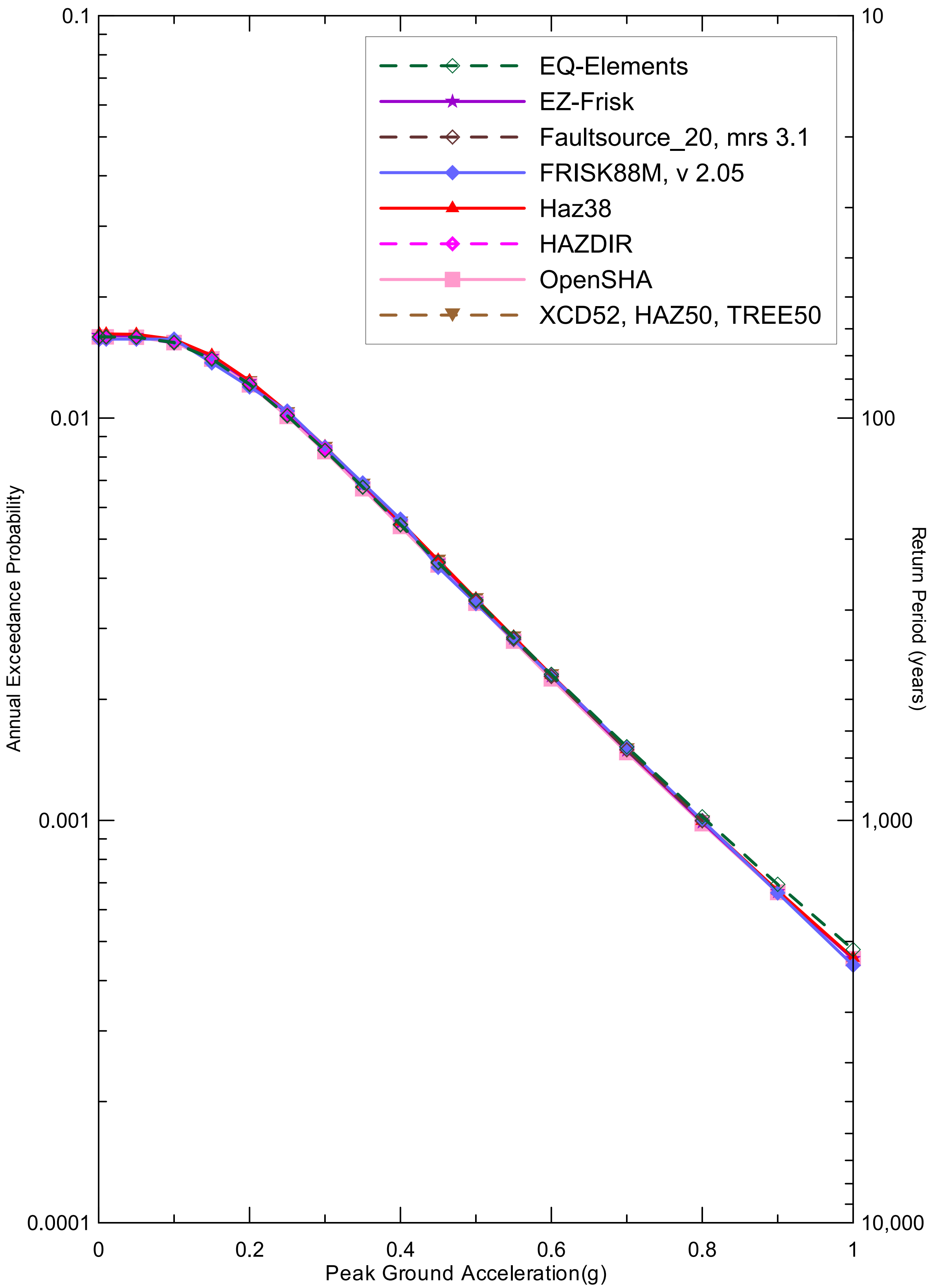
PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 3	Figure 3.58



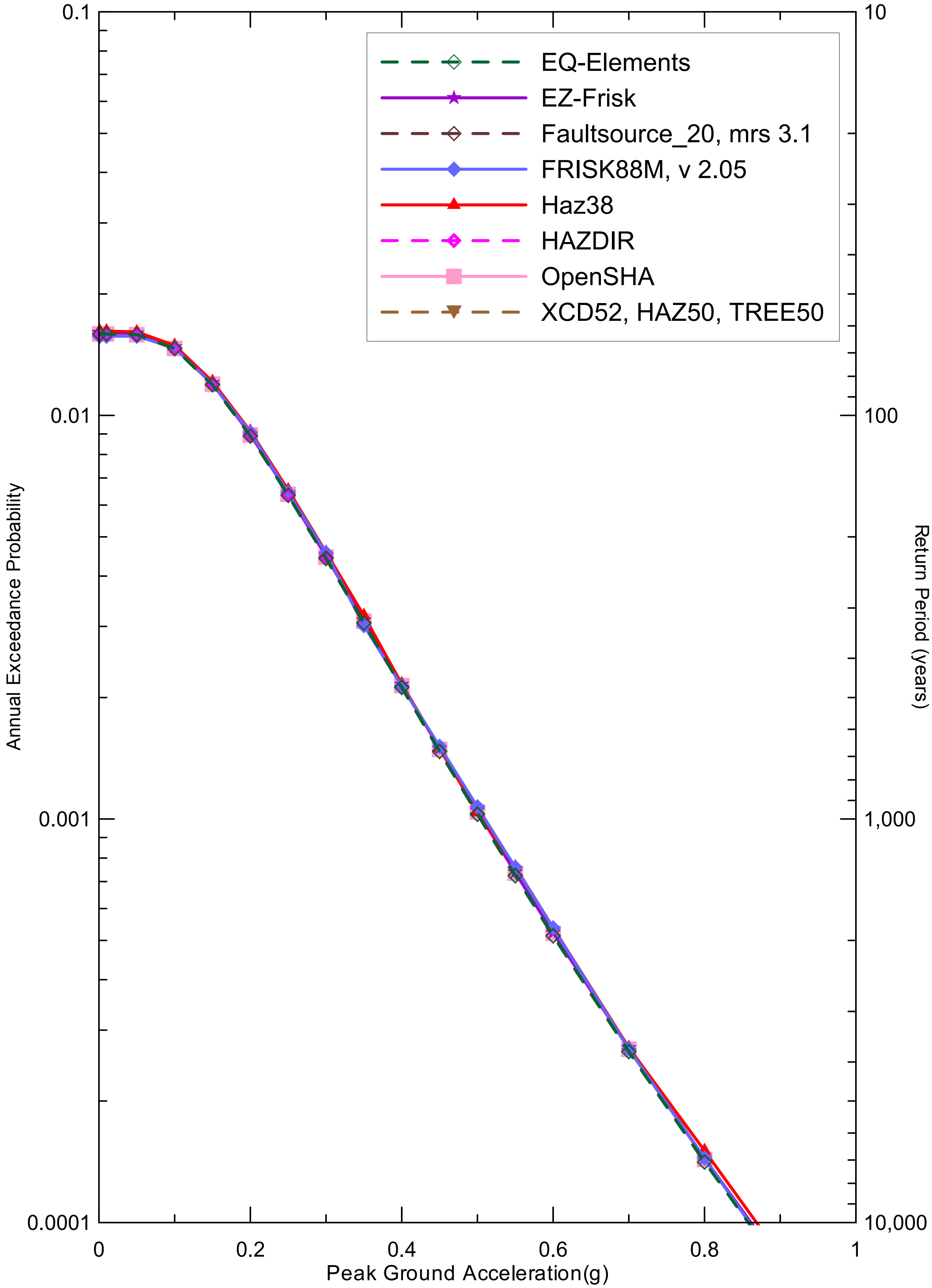
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 4	Figure 3.59



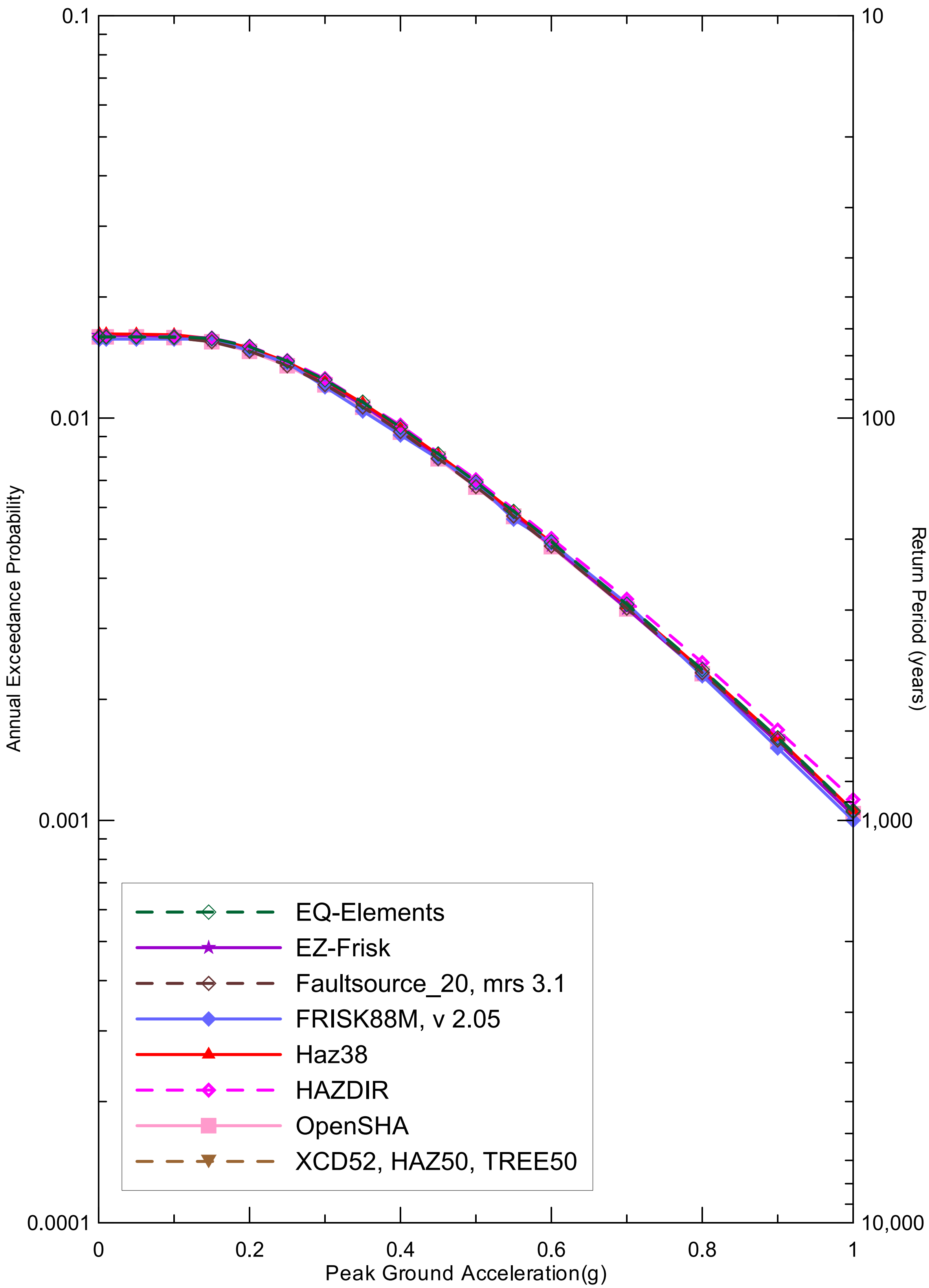
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 5	Figure 3.60



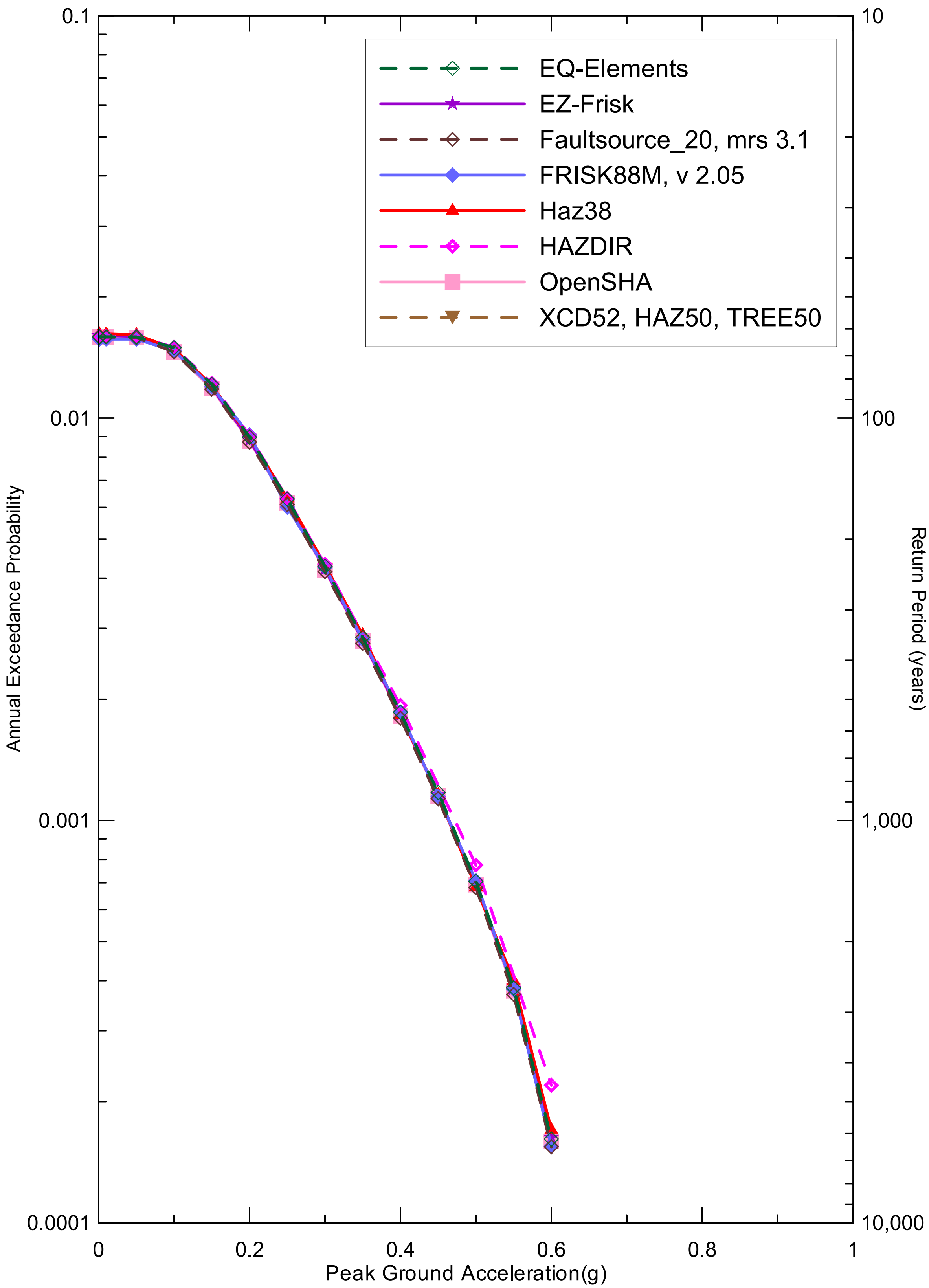
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 6	Figure 3.61



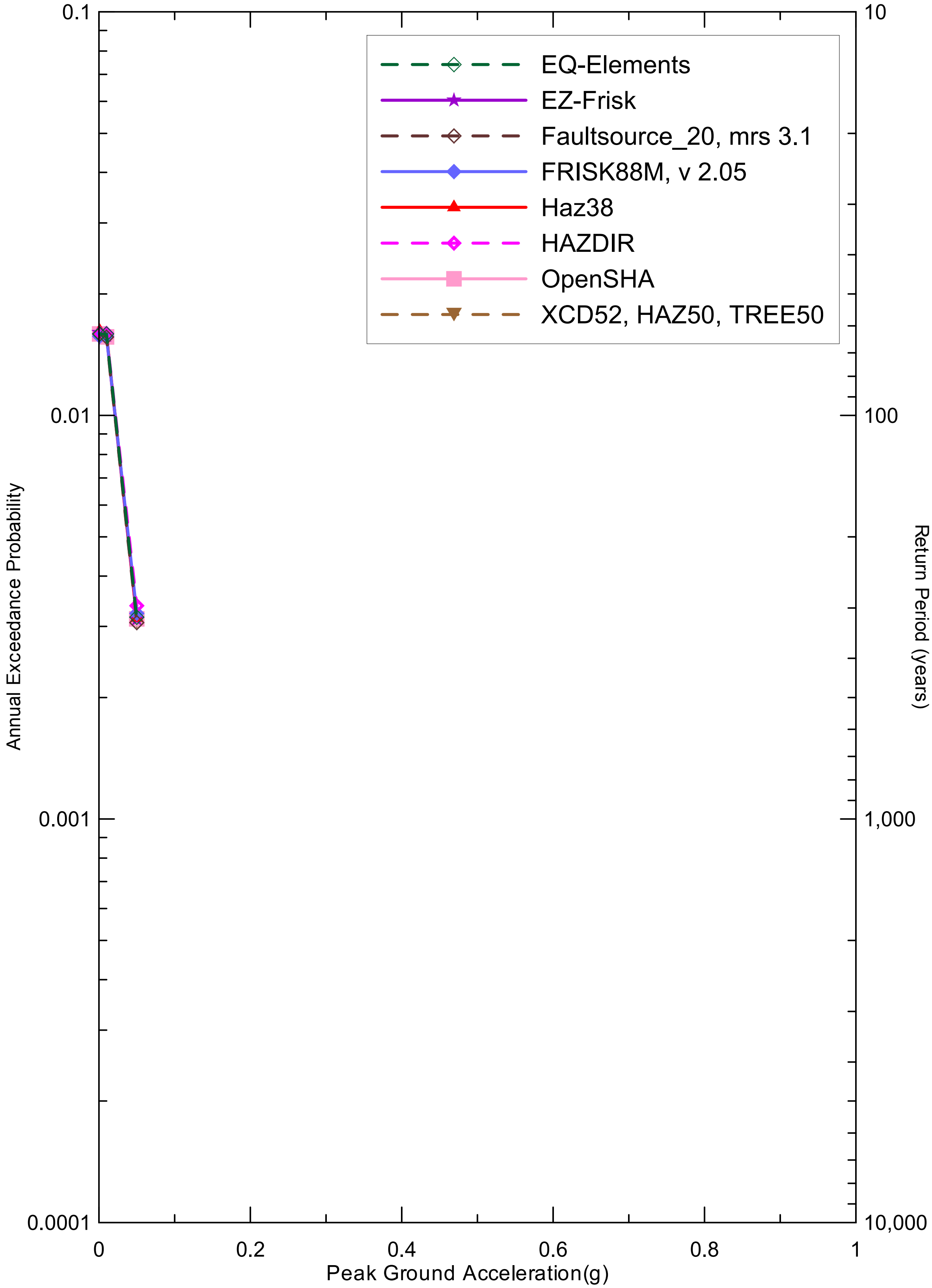
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8a, SITE 7	Figure 3.62



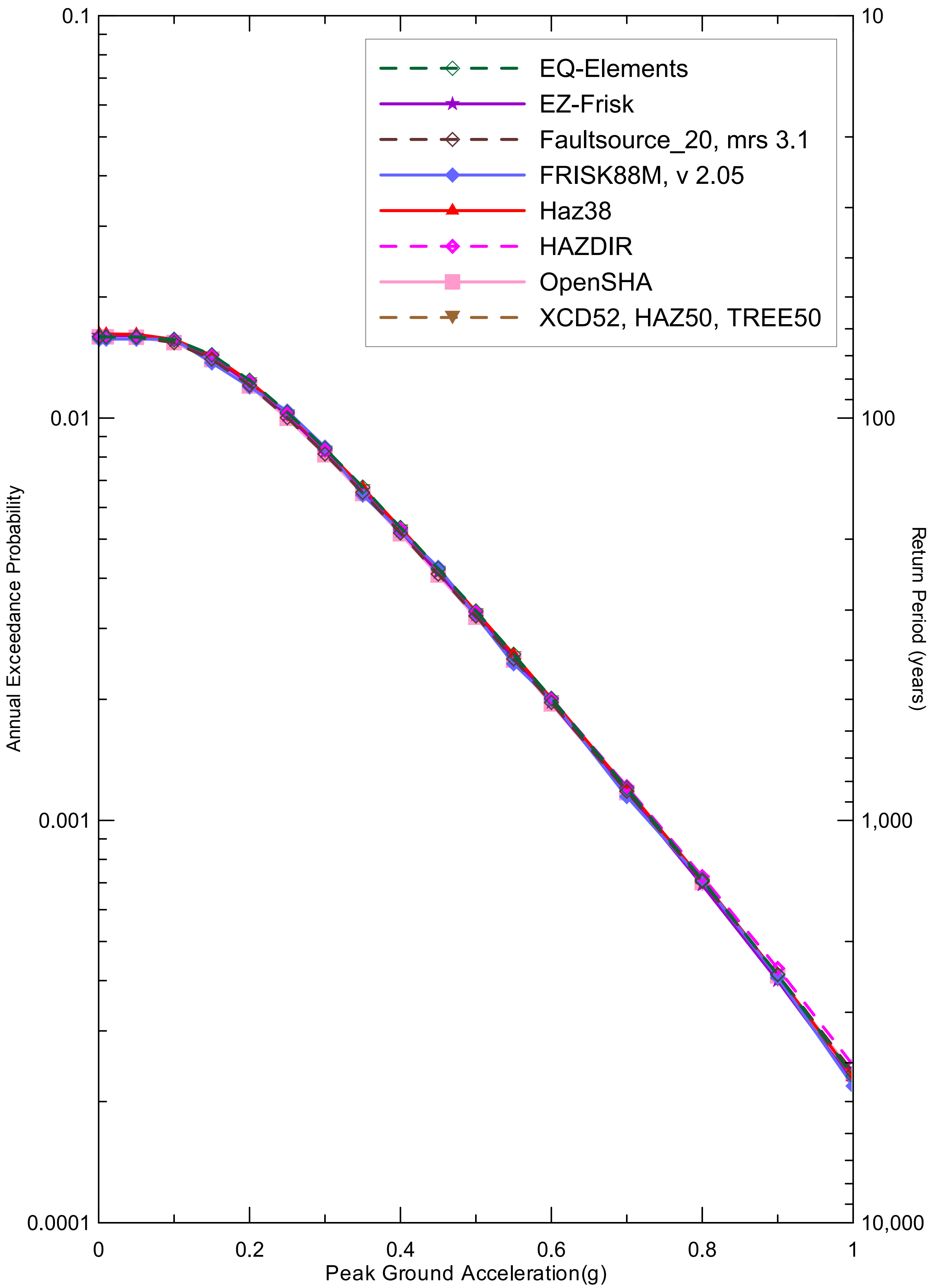
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 1	Figure 3.63



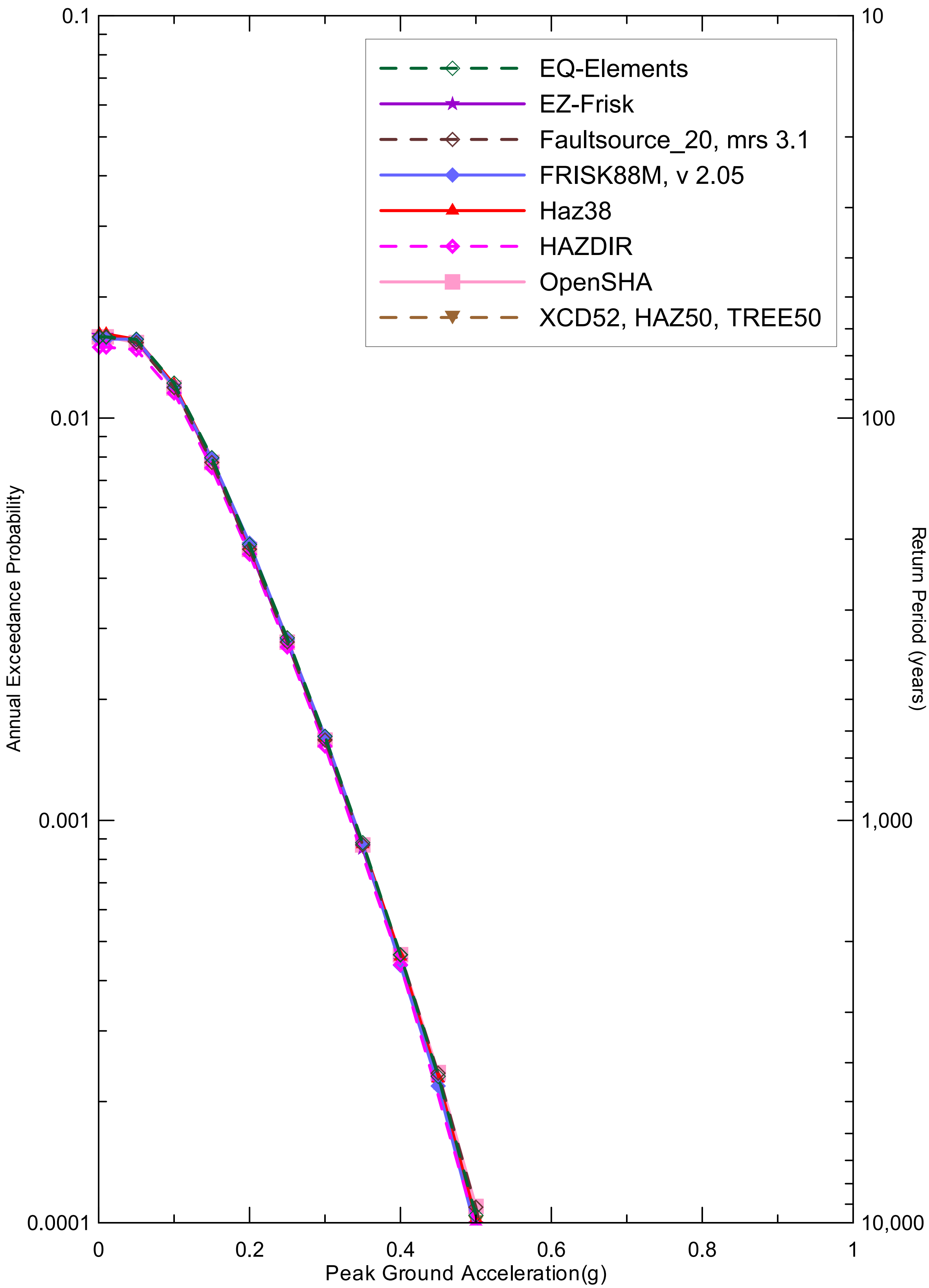
PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 2	Figure 3.64



	PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 3	Figure 3.65



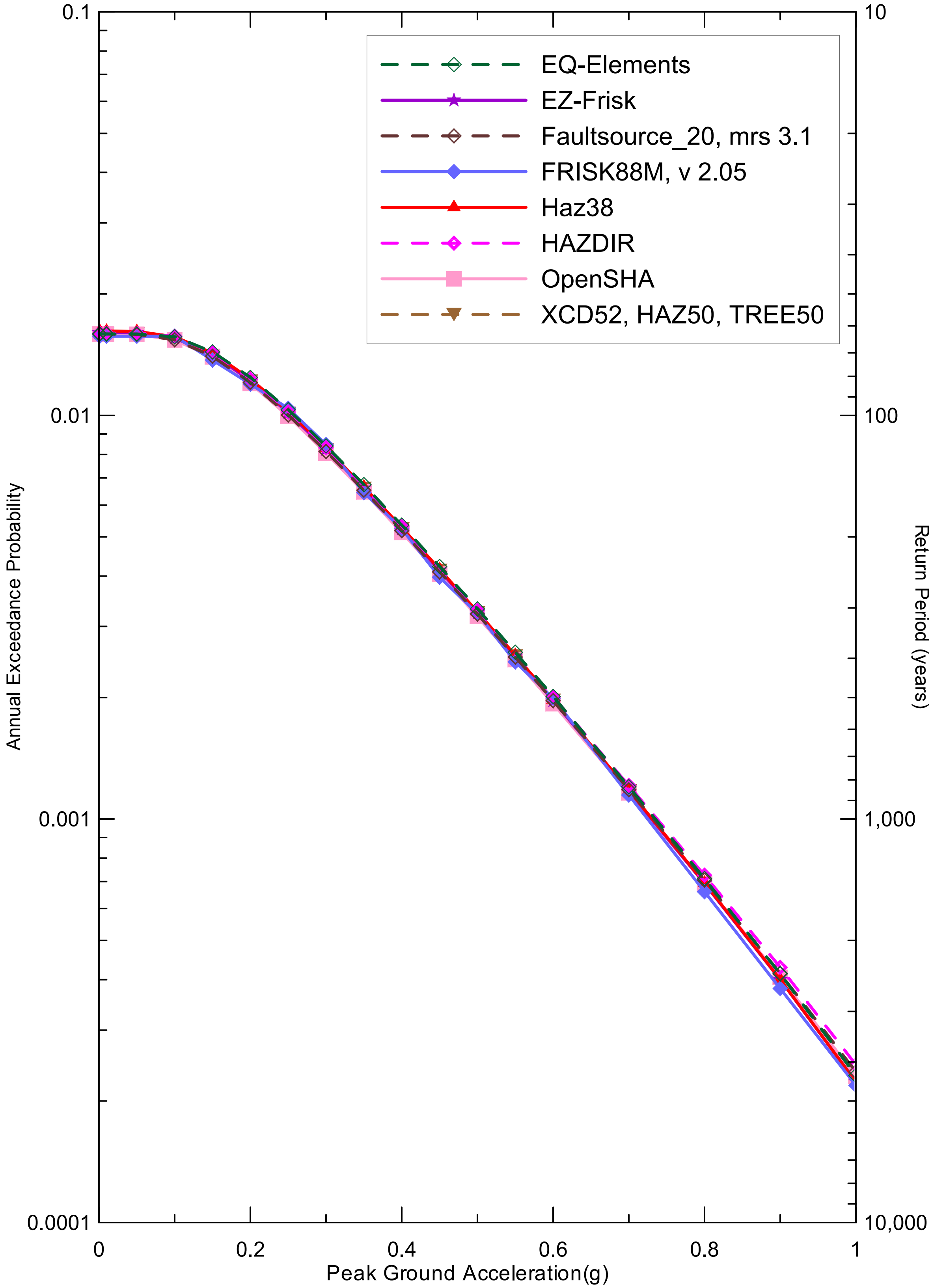
PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 4	Figure 3.66



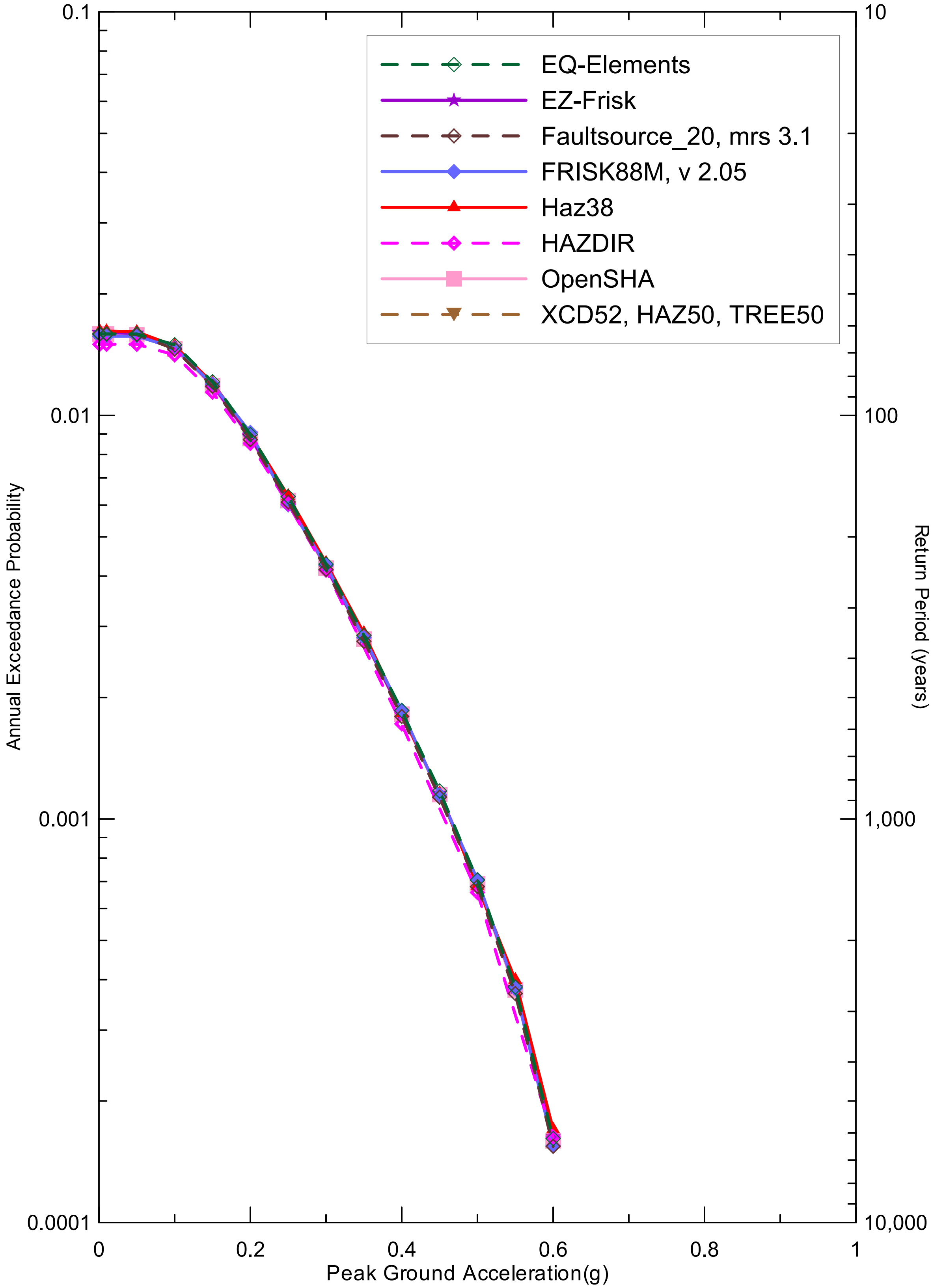
PEER PSHA VERIFICATION

TEST SET 1, CASE 8b, SITE 5

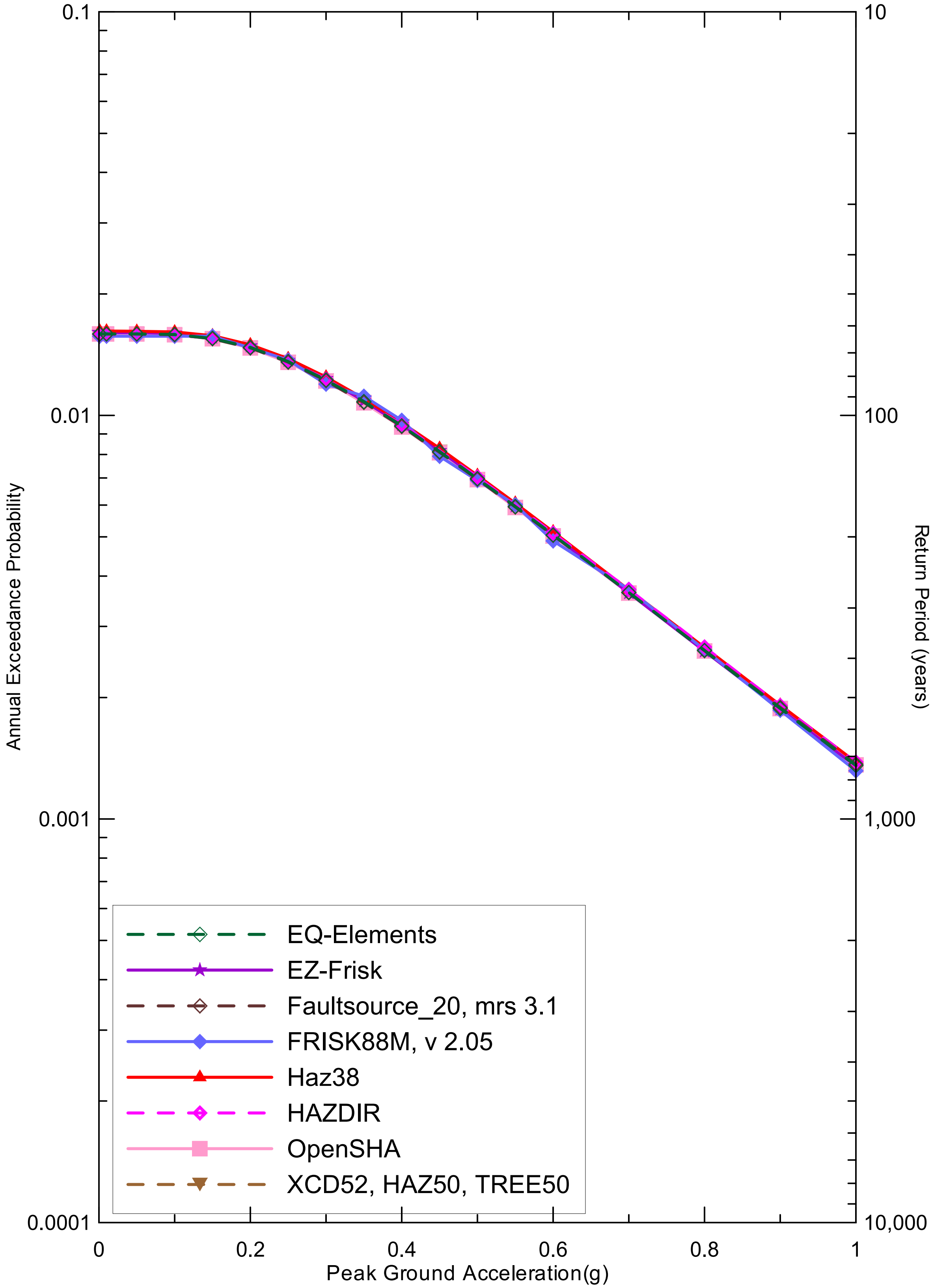
Figure 3.67



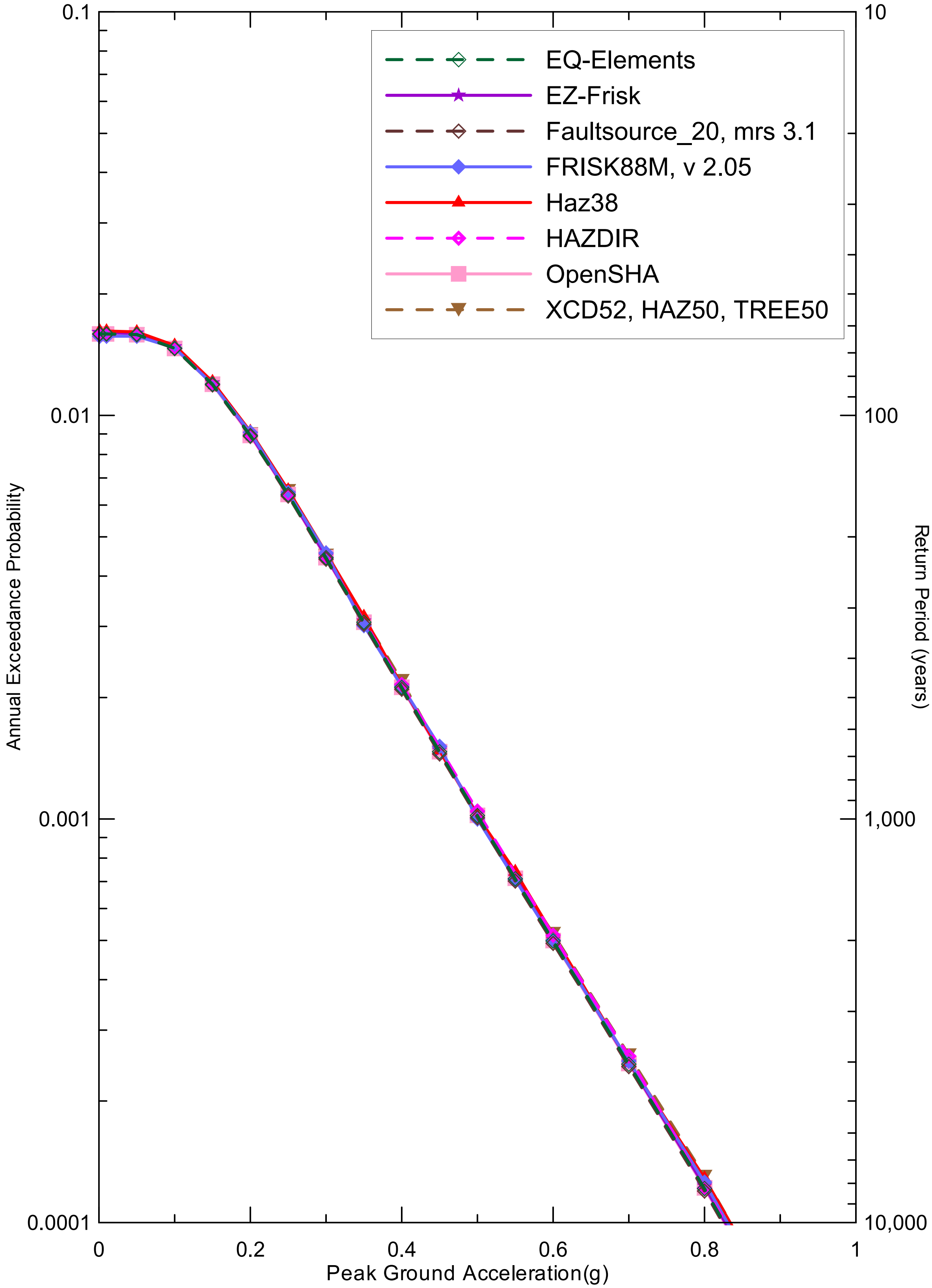
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 6	Figure 3.68



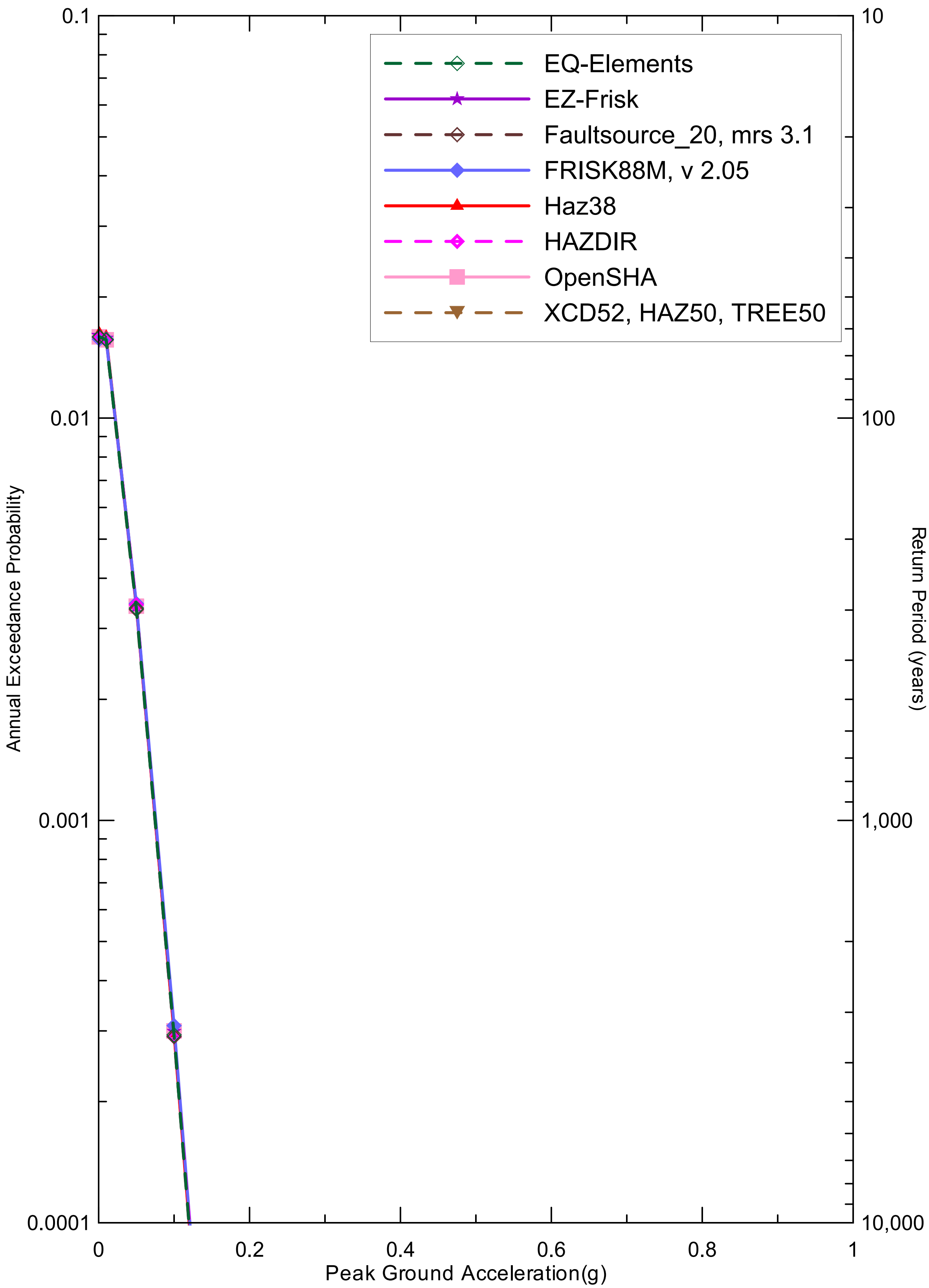
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8b, SITE 7	Figure 3.69



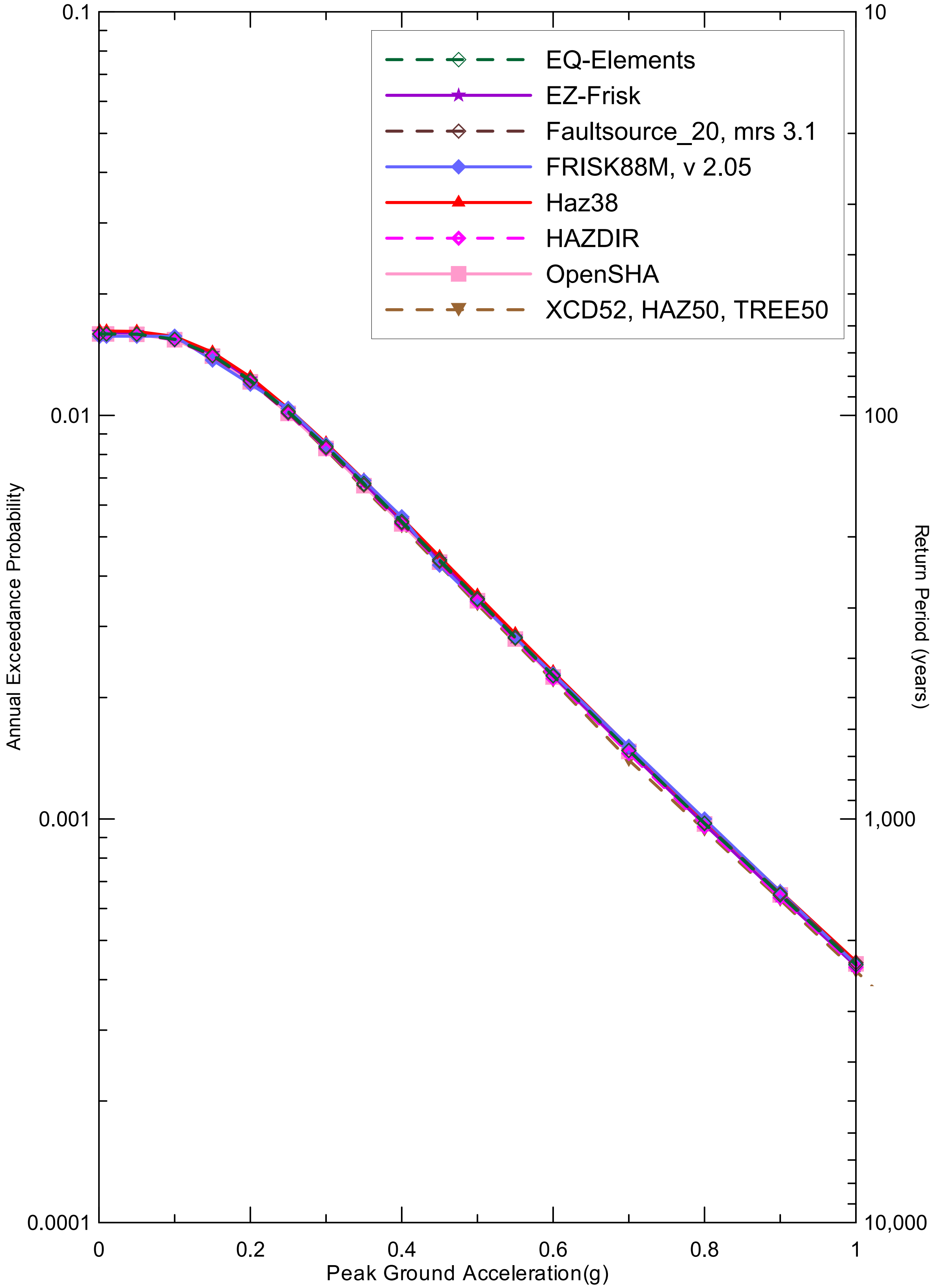
PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 2	Figure 3.70



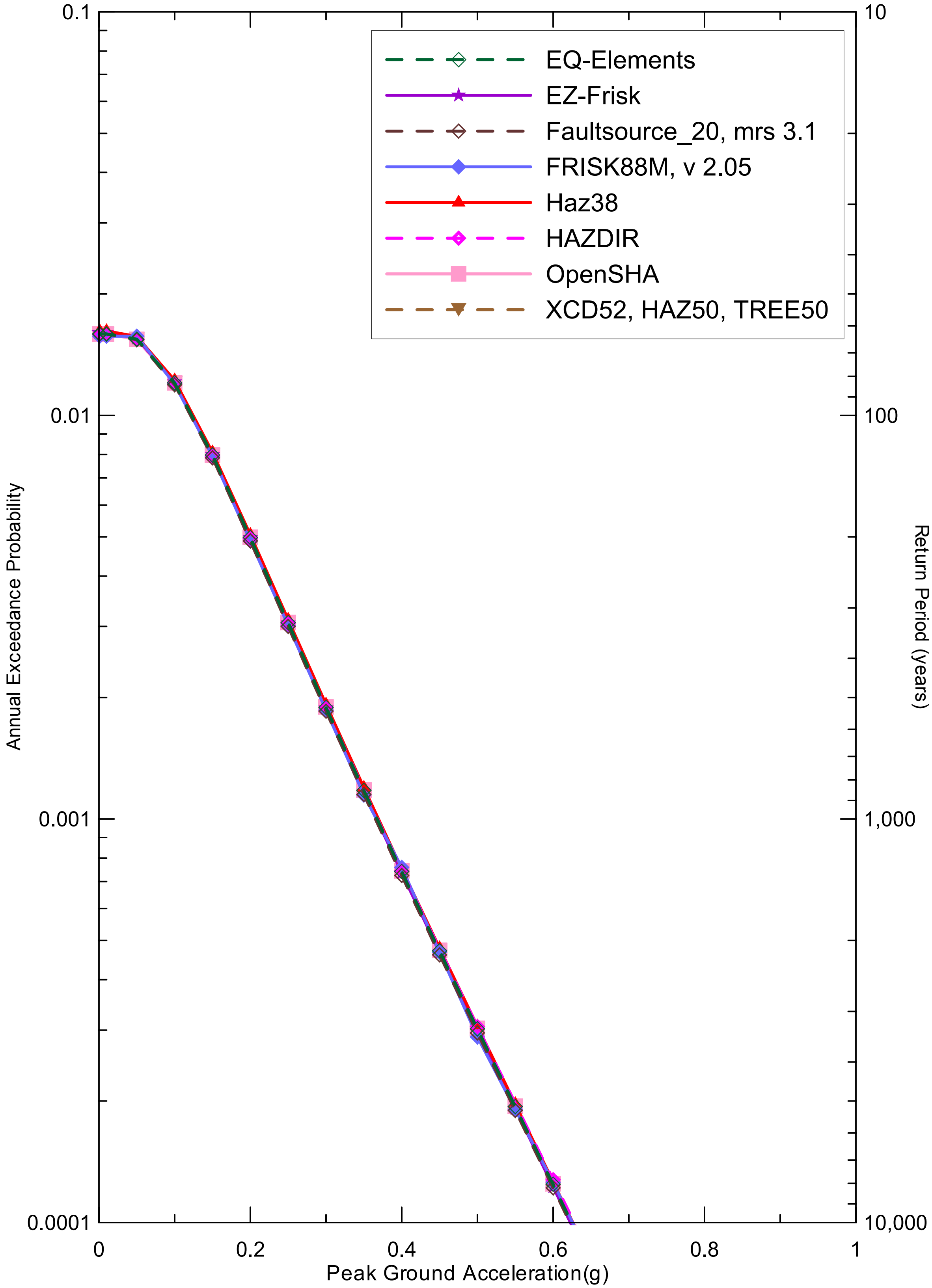
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 2	Figure 3.71



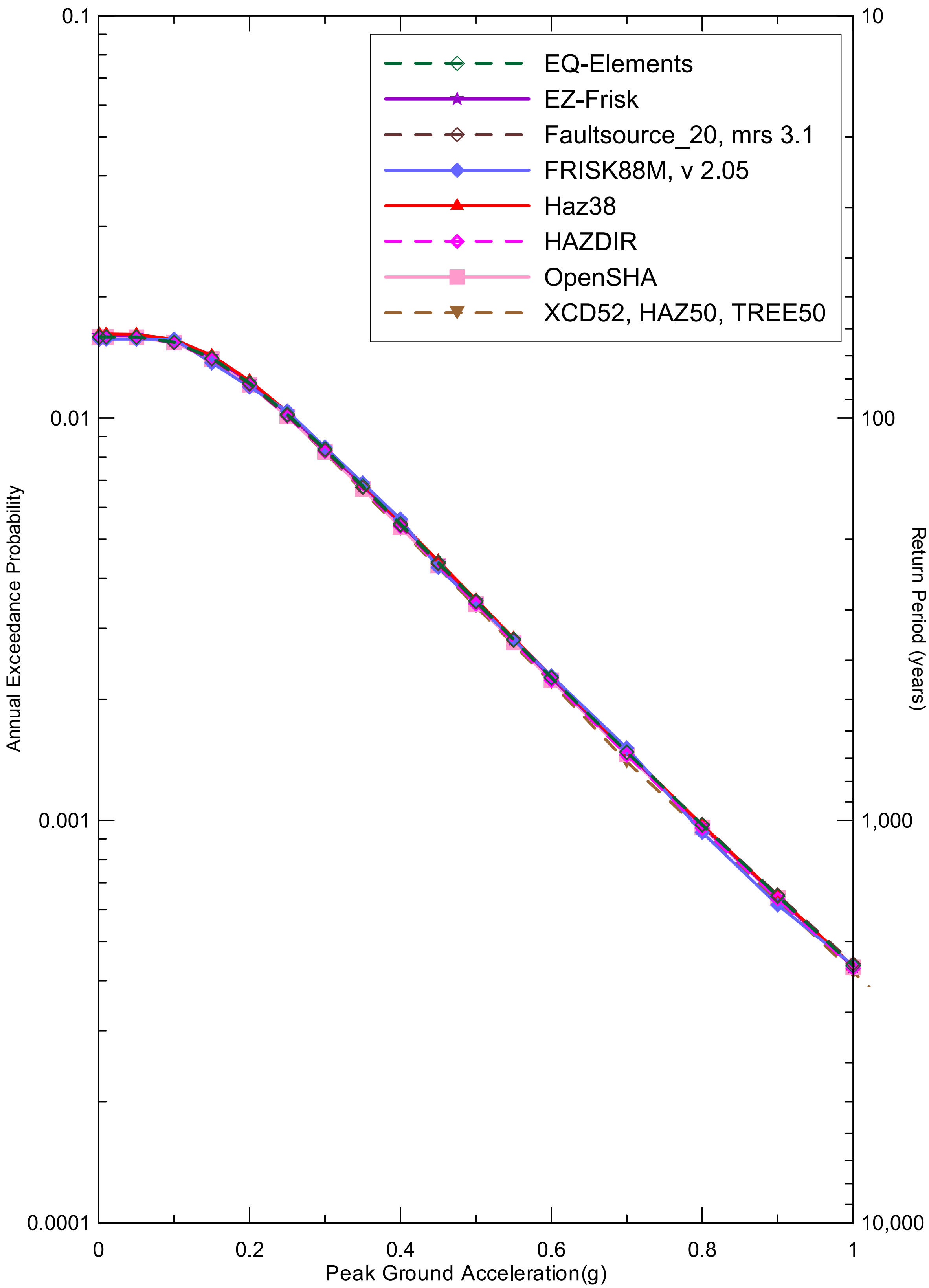
PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 3	Figure 3.72



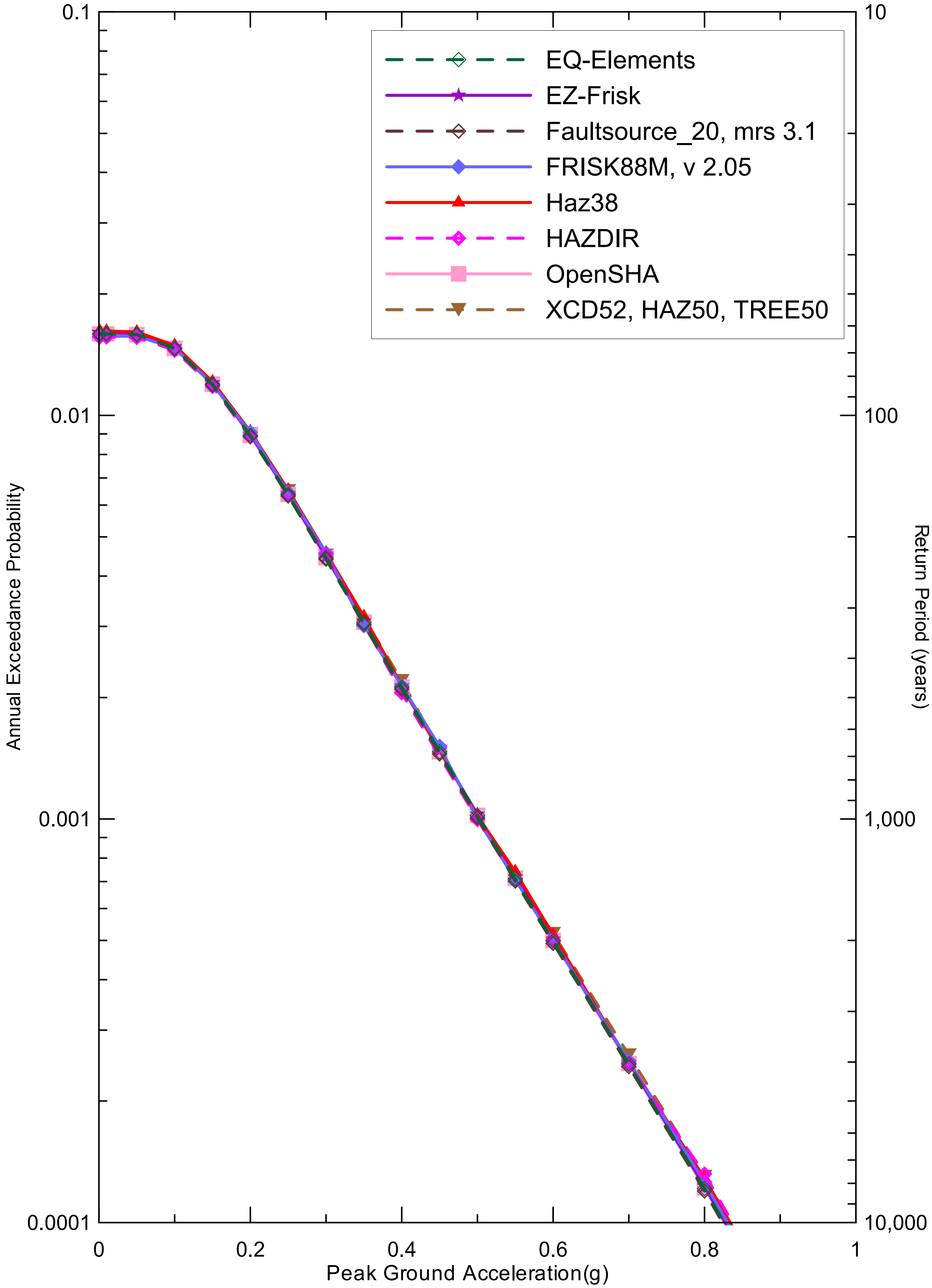
PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 4	Figure 3.73



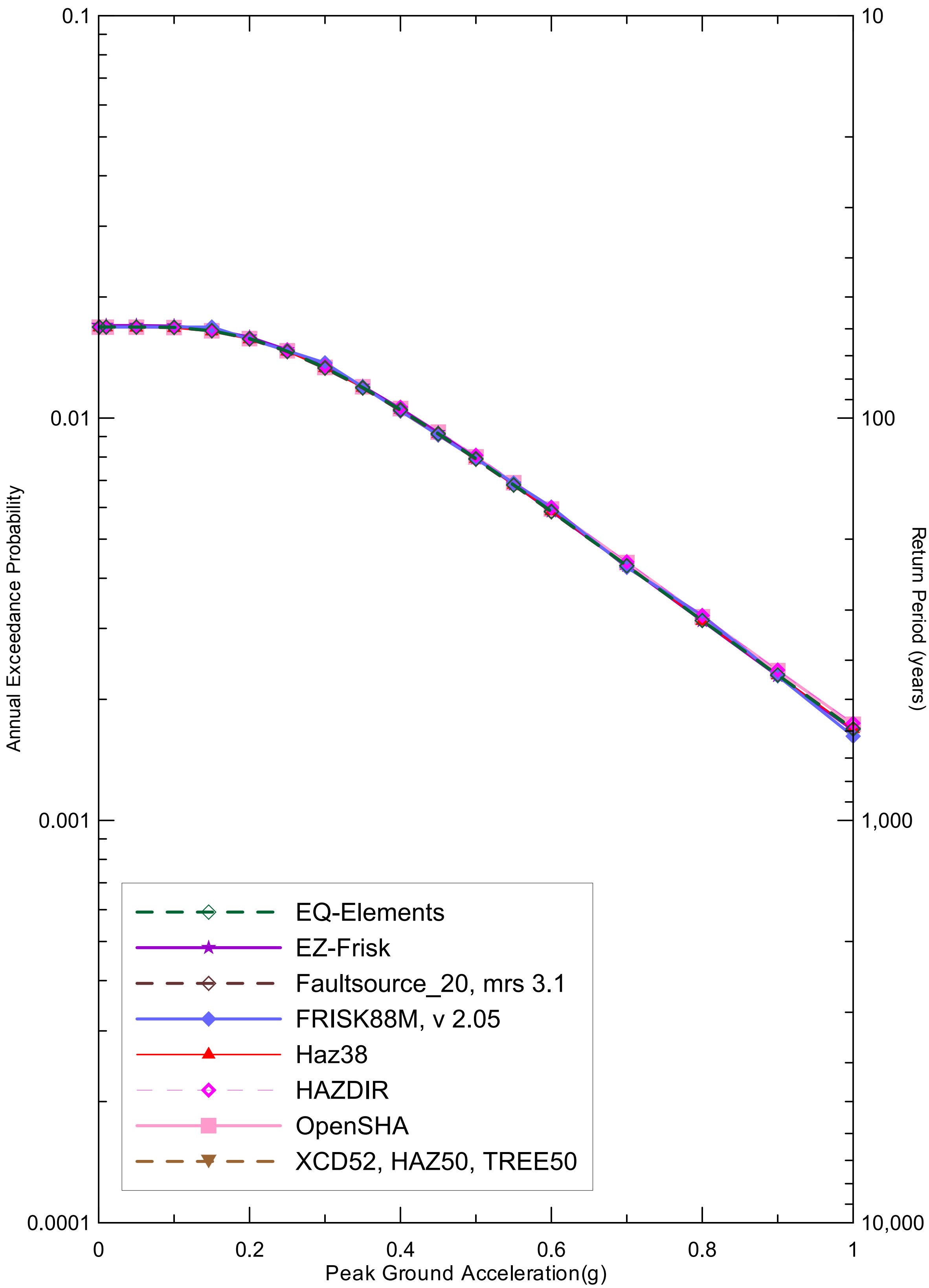
PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 5	Figure 3.74



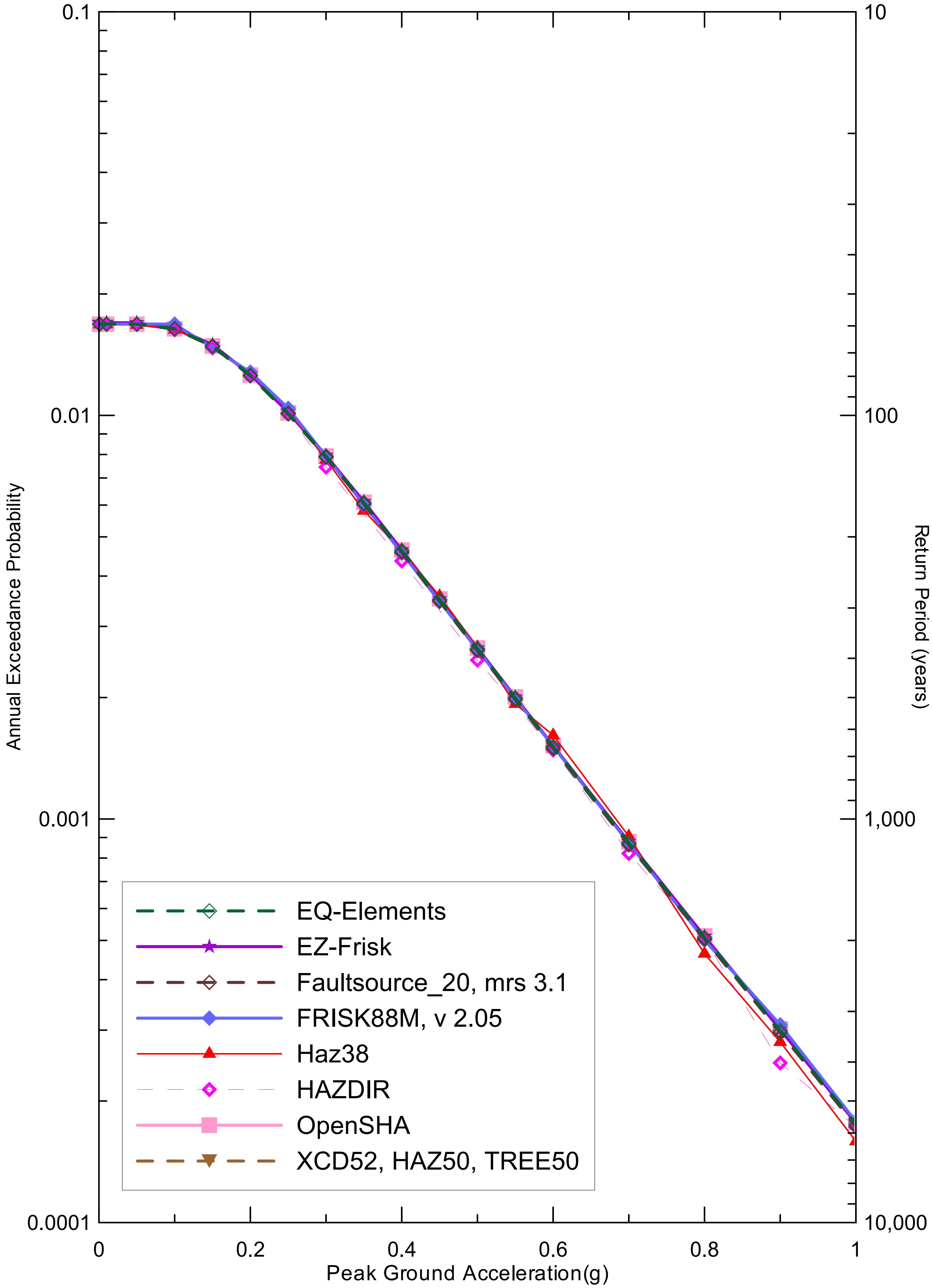
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 6	Figure 3.75



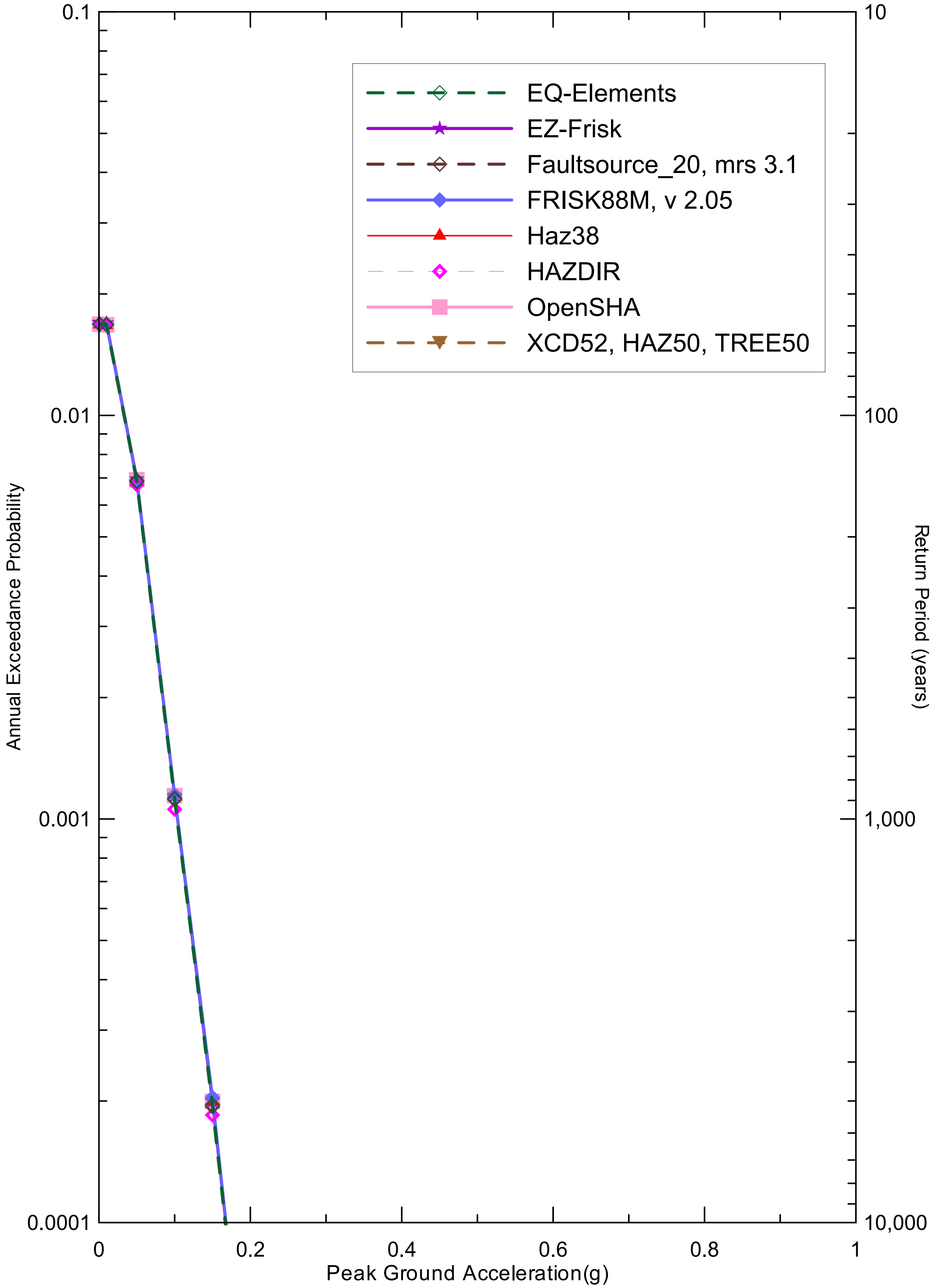
	PEER PSHA VERIFICATION	TEST SET 1, CASE 8c, SITE 7	Figure 3.76



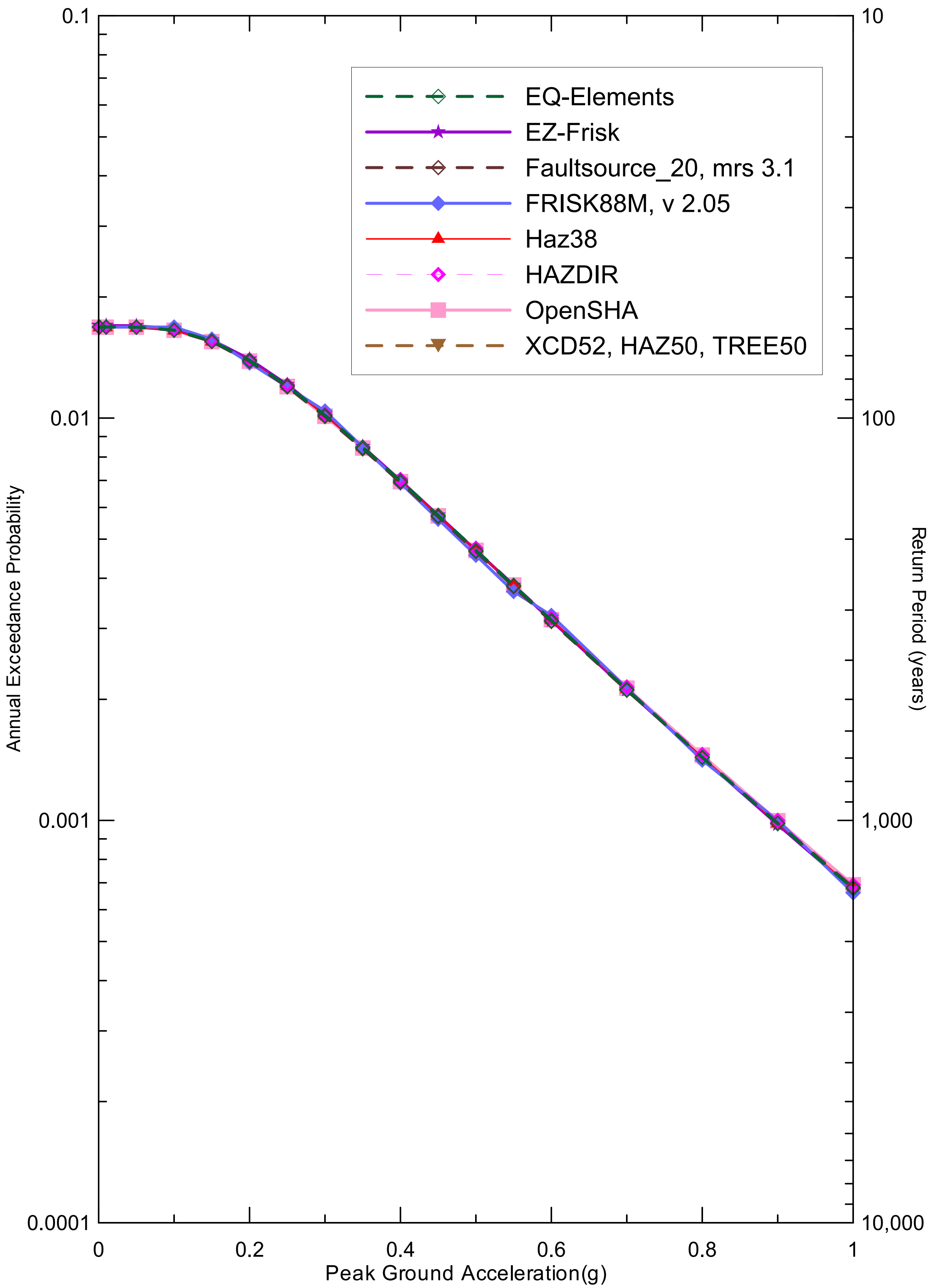
PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 1	Figure 3.77



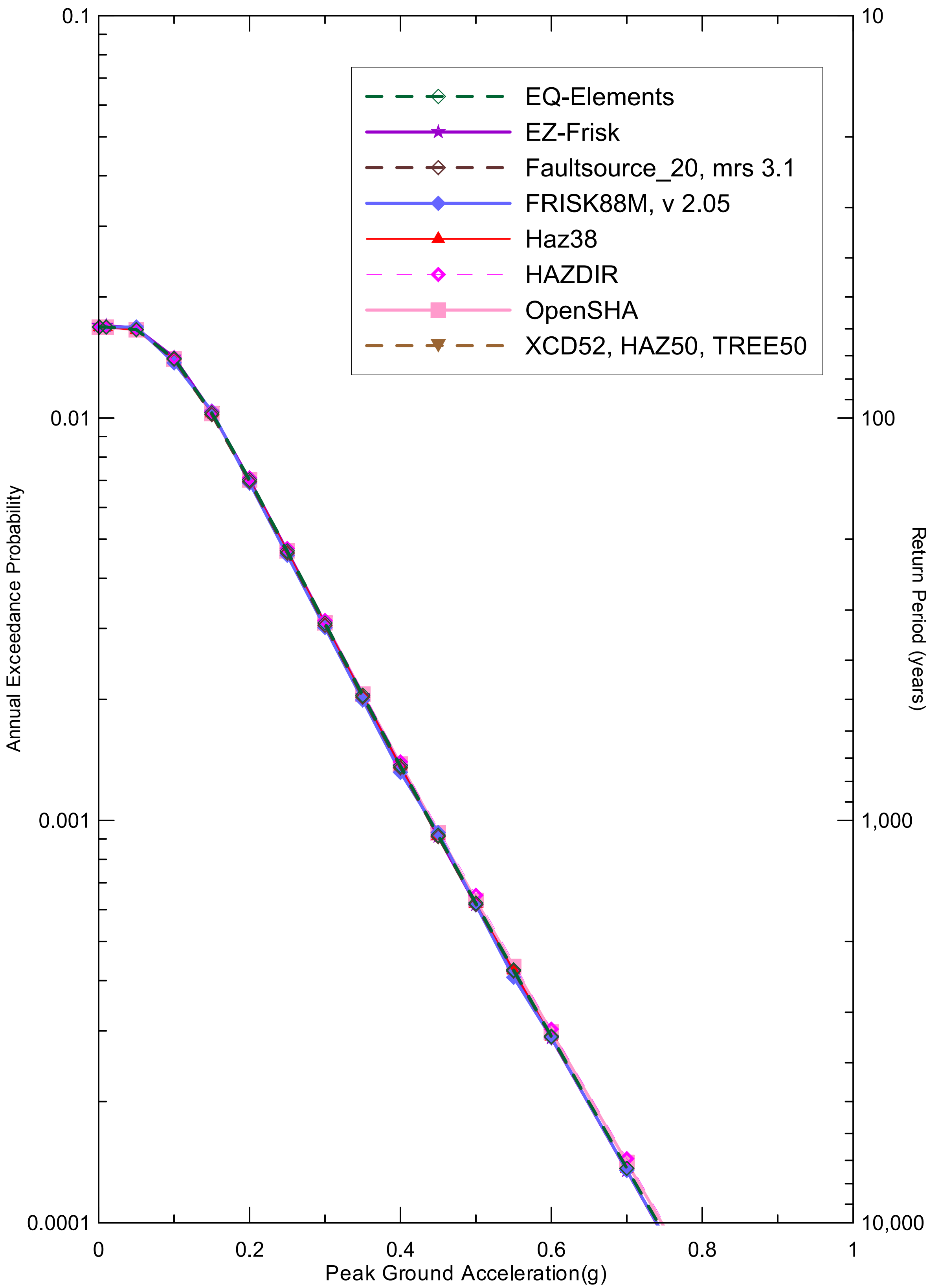
PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 2	Figure 3.78



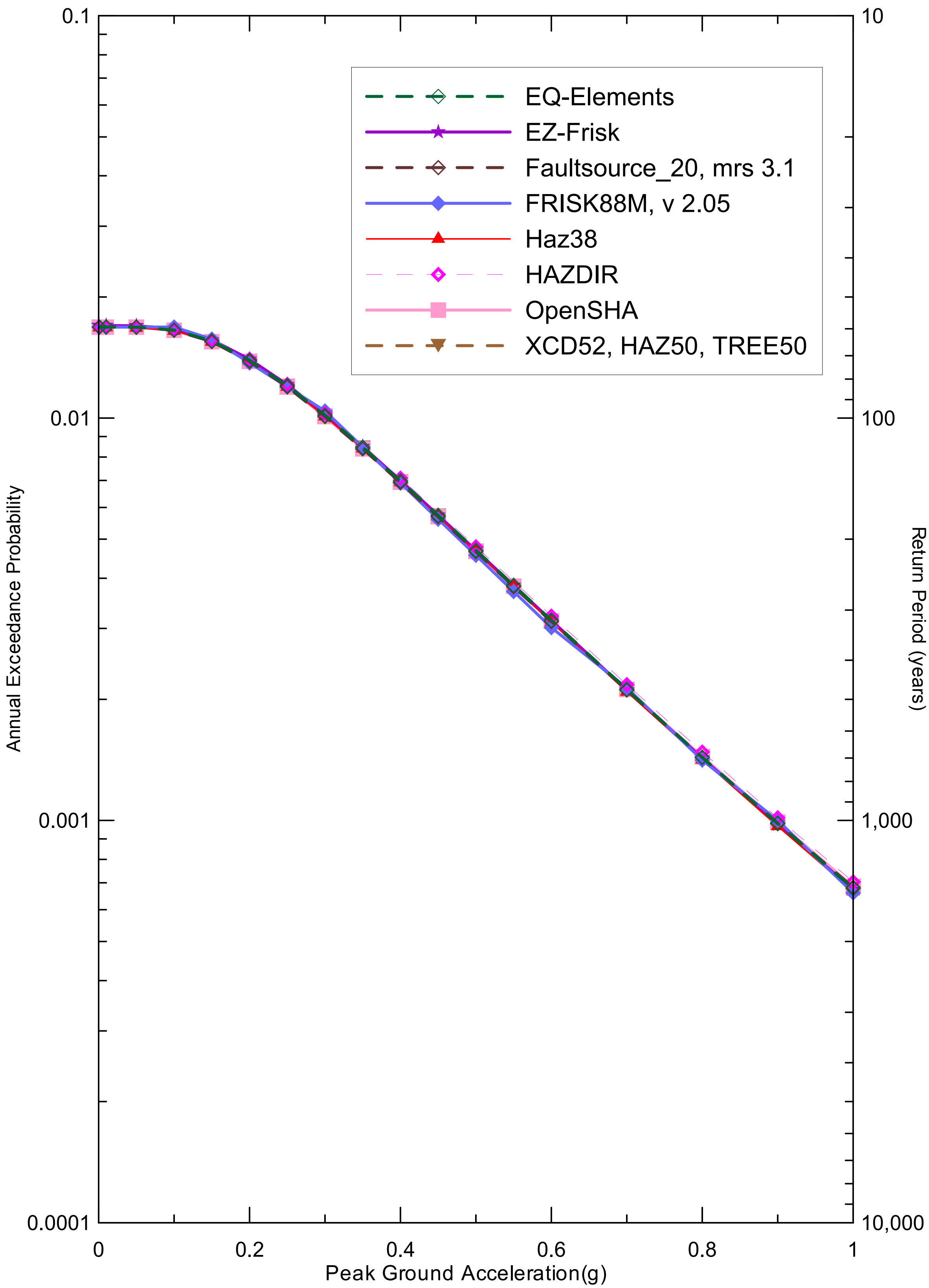
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 3	Figure 3.79



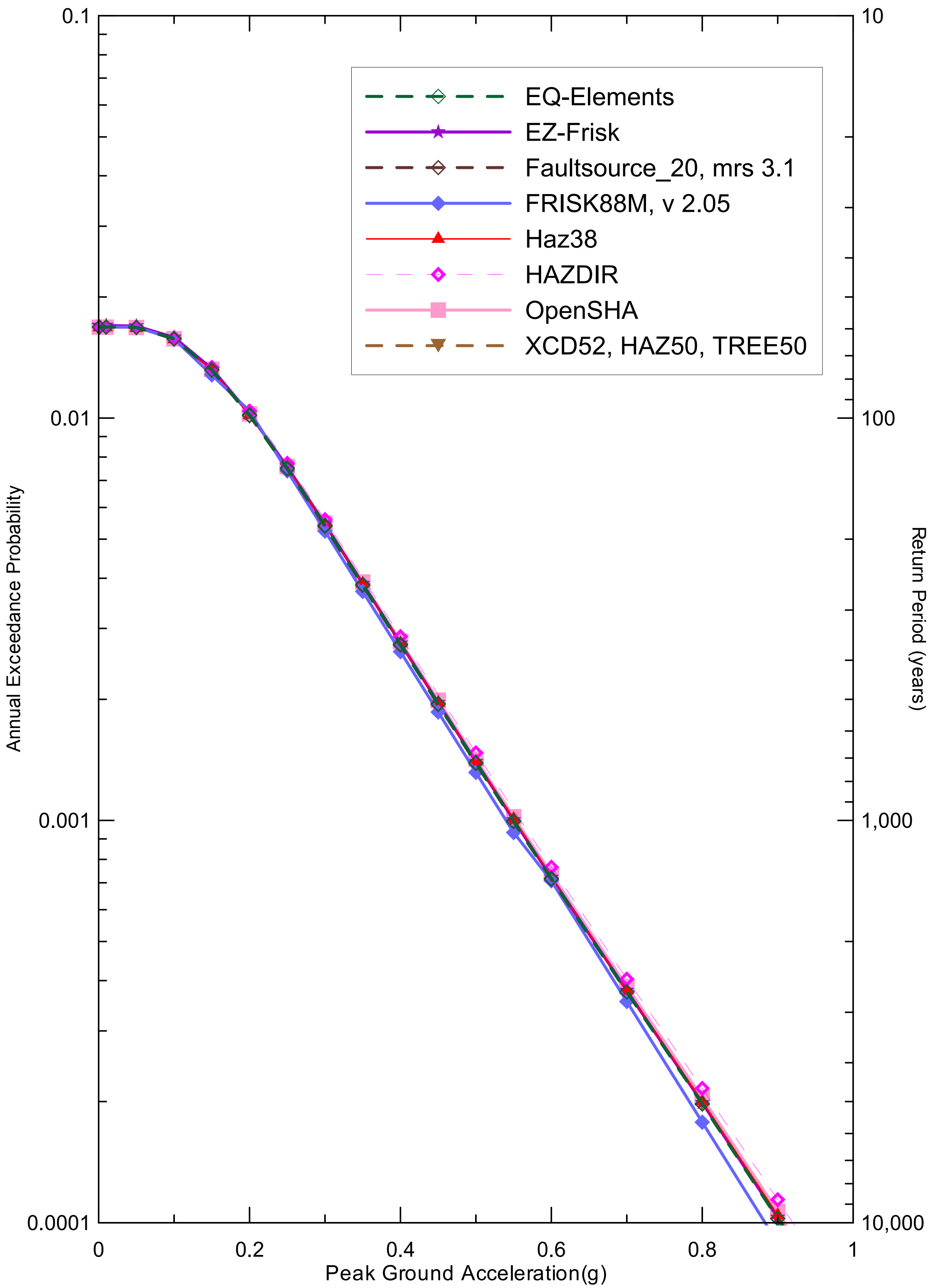
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 4	Figure 3.80



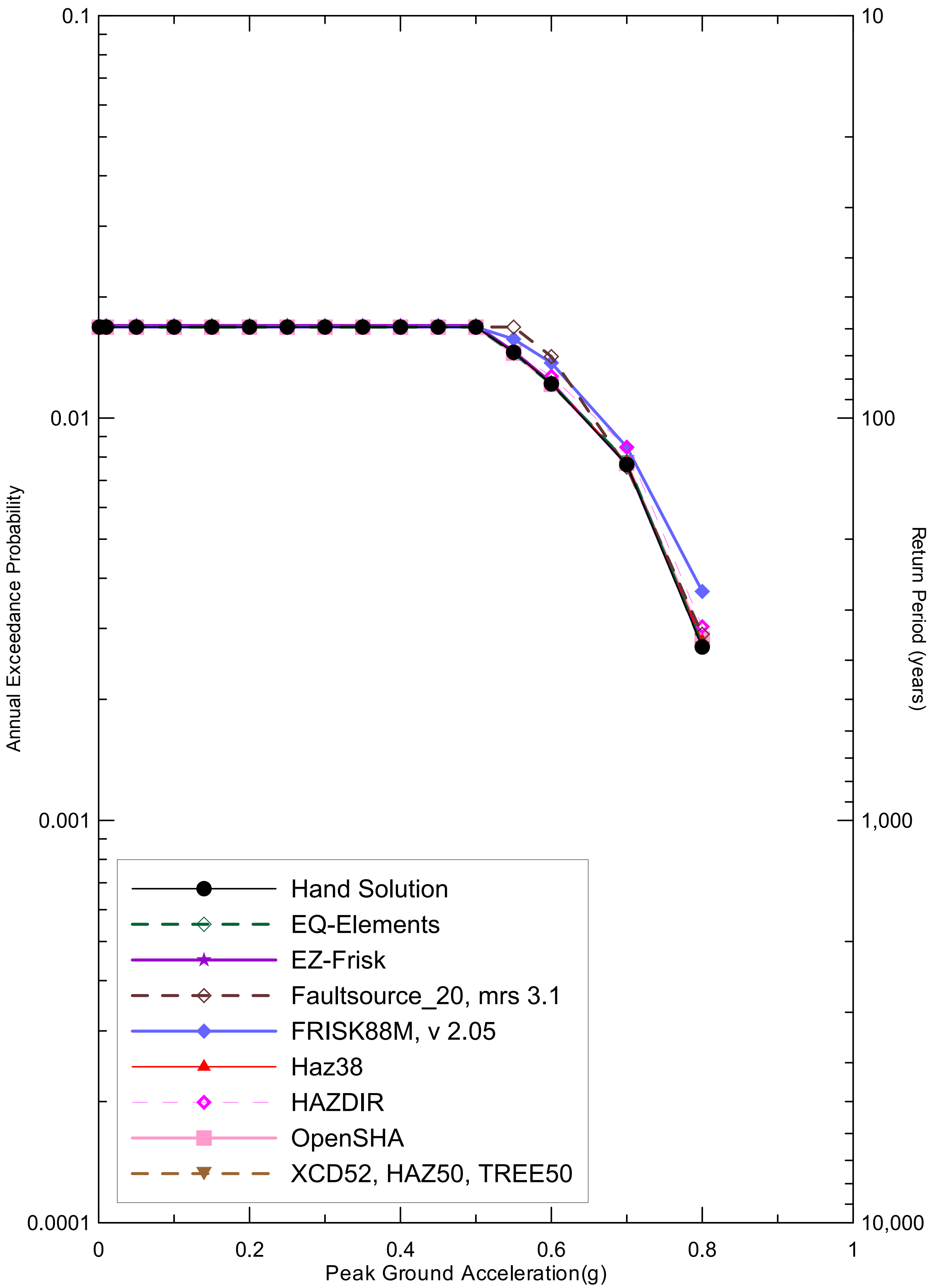
PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 5	Figure 3.81



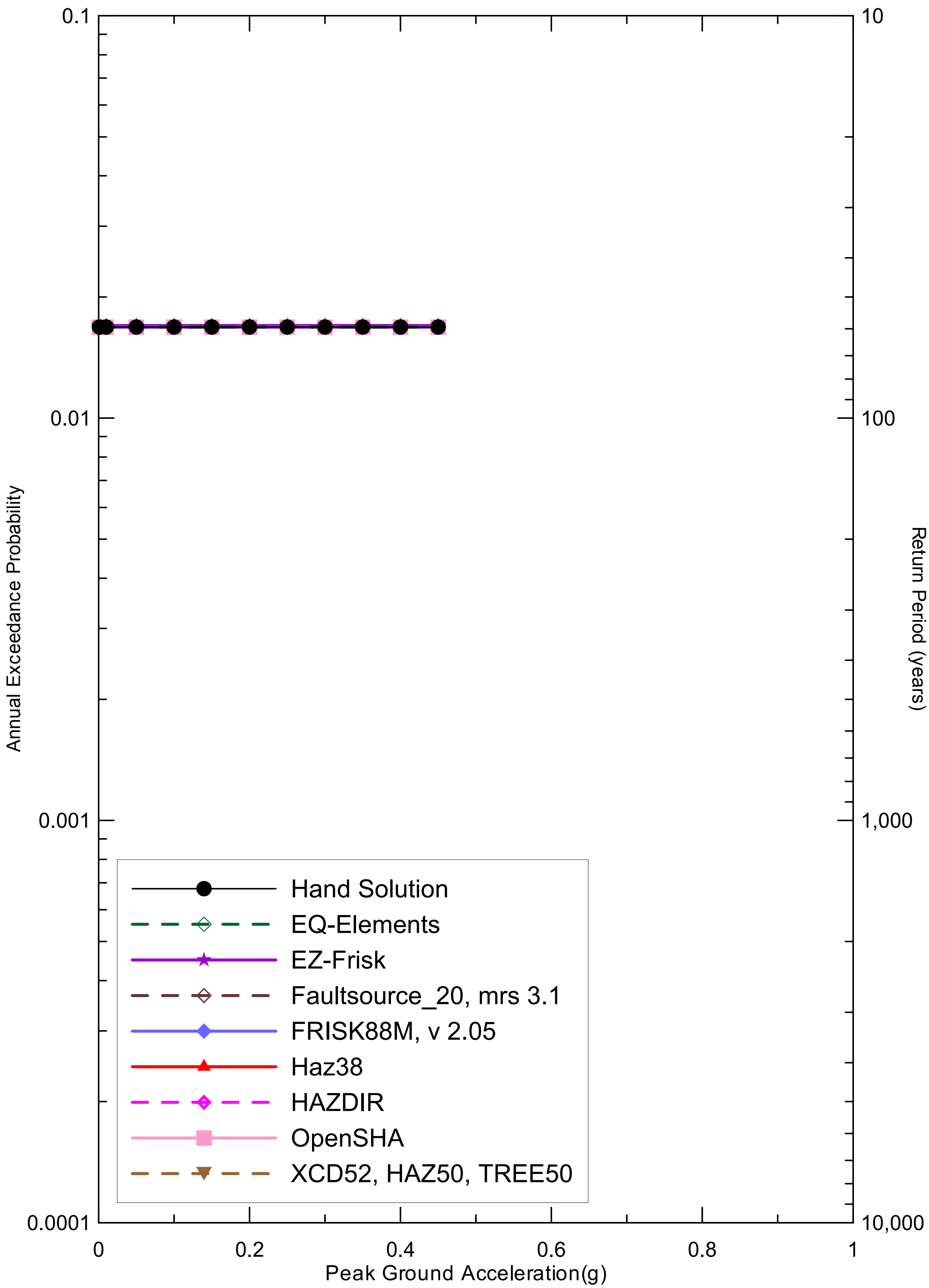
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 6	Figure 3.82



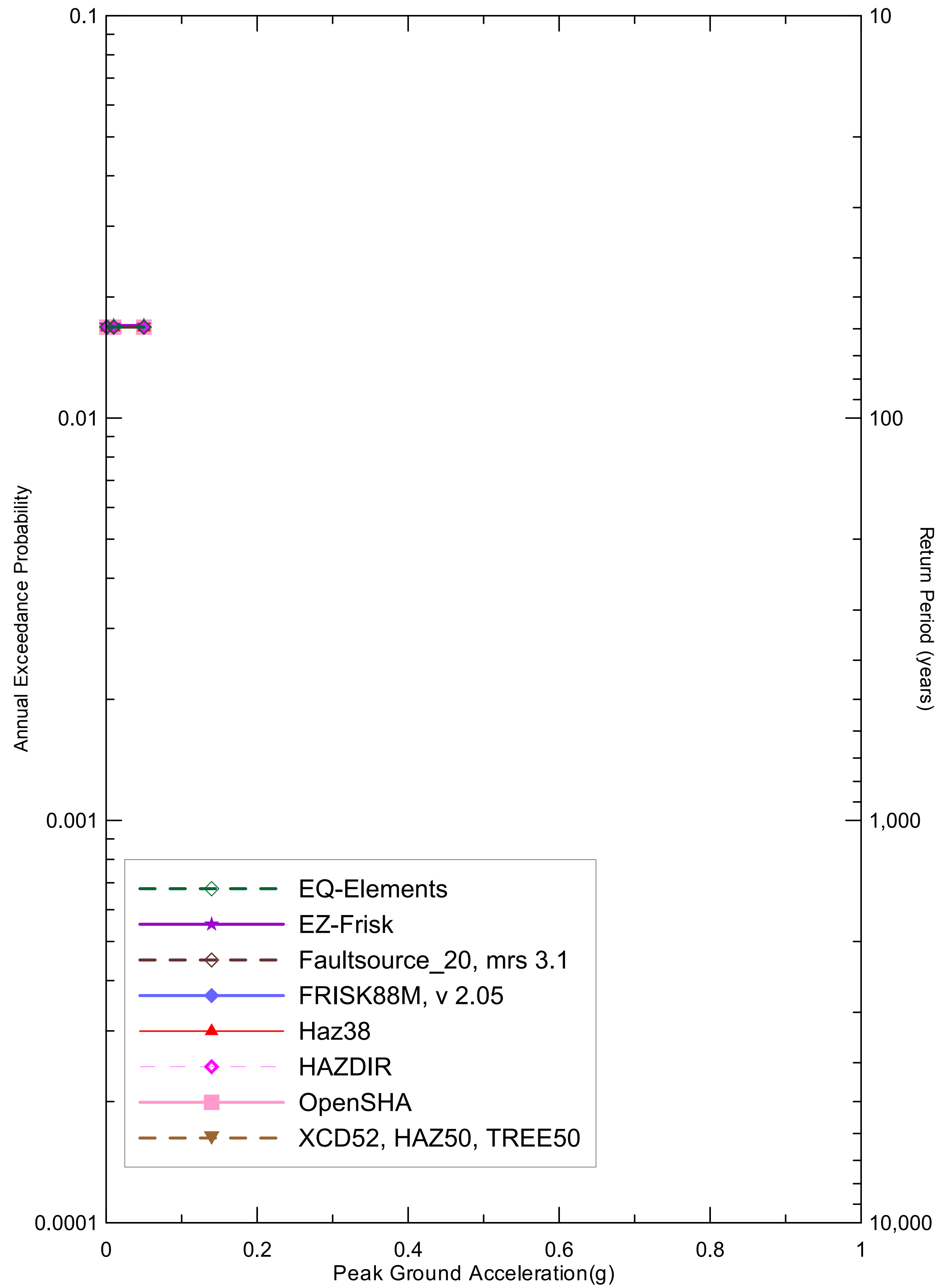
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9a, SITE 7	Figure 3.83



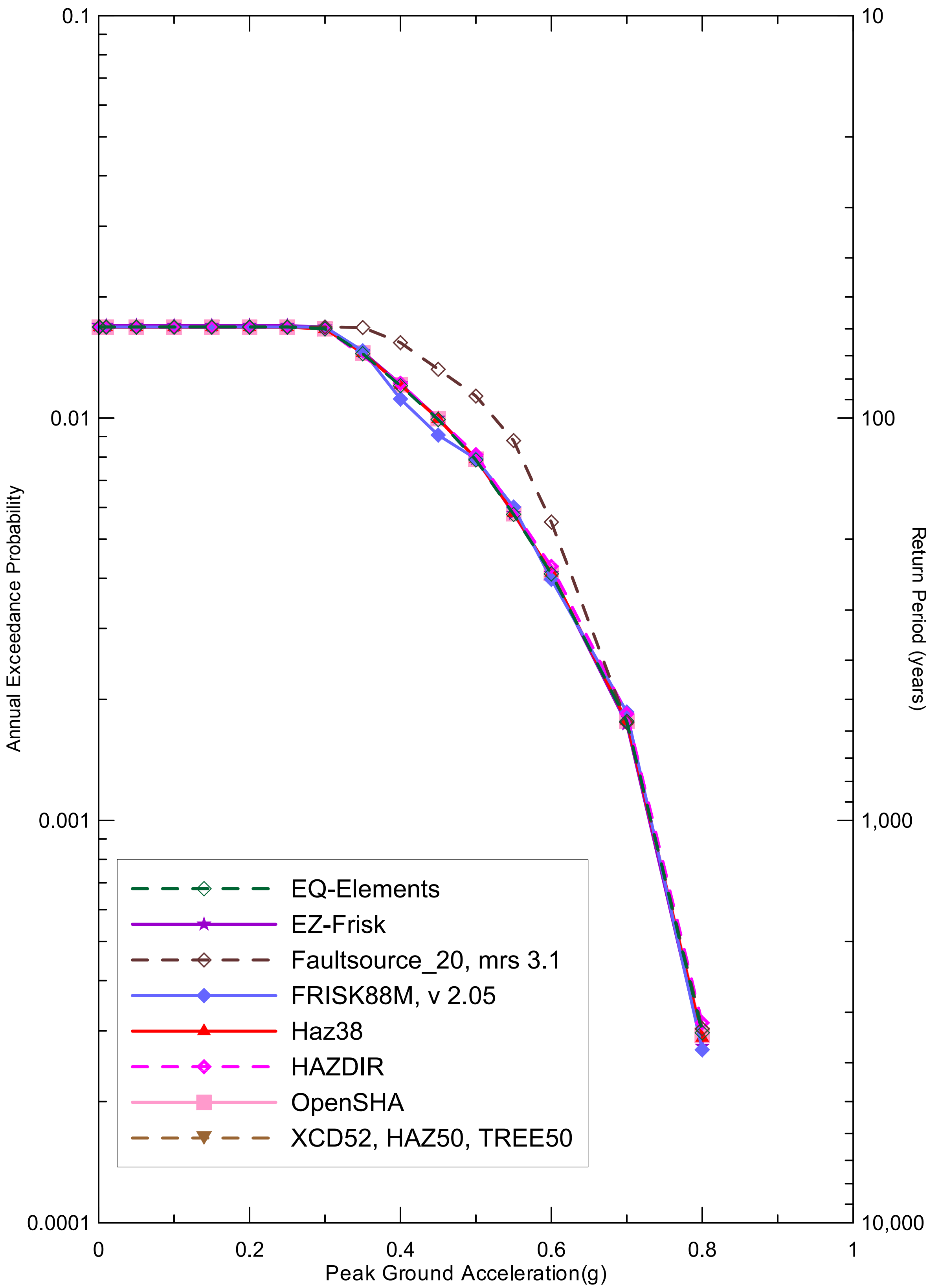
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 1	Figure 3.84



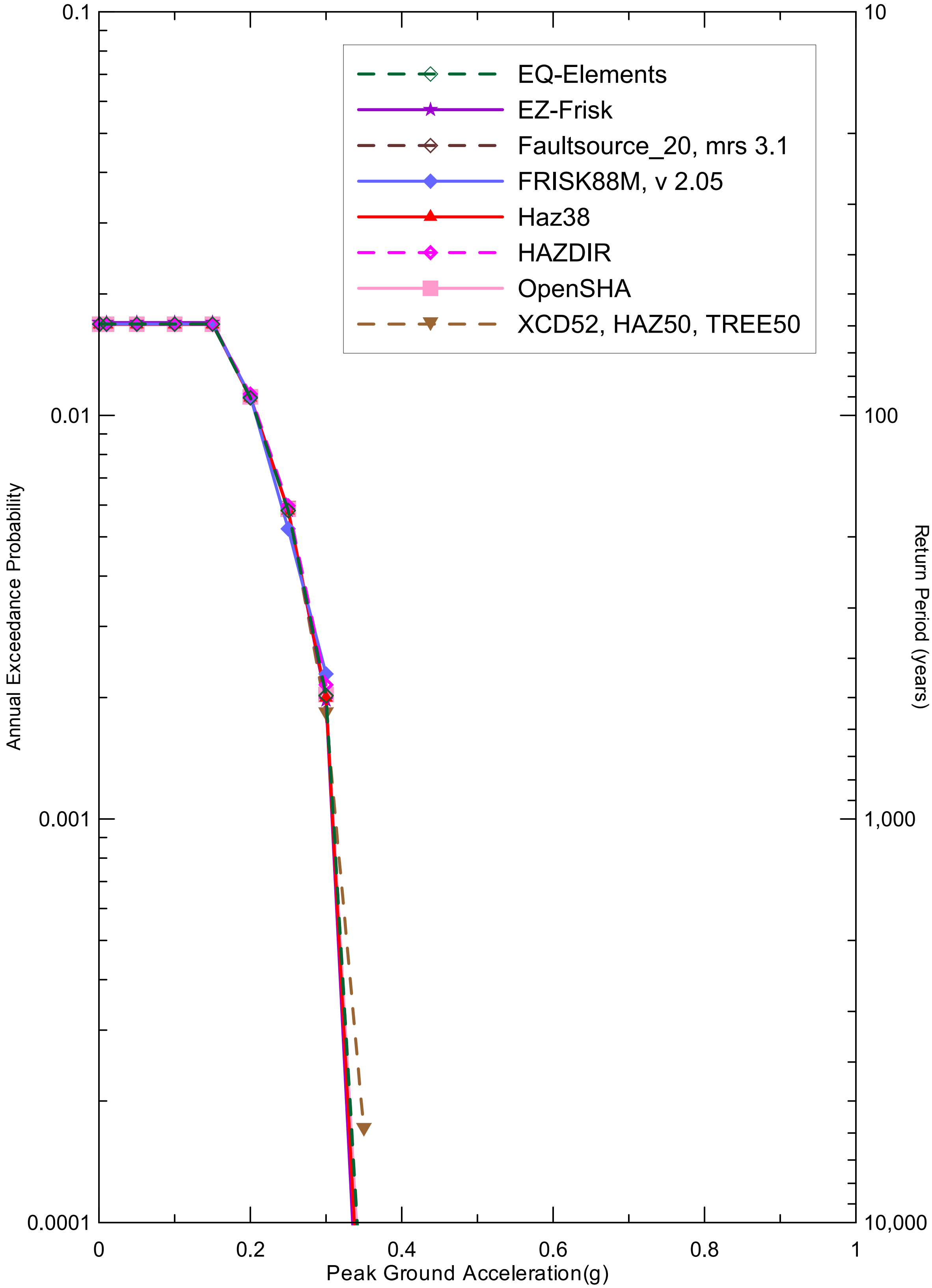
PEER PSHA VERIFICATION		TEST SET 1, CASE 9b, SITE 2	Figure 3.85



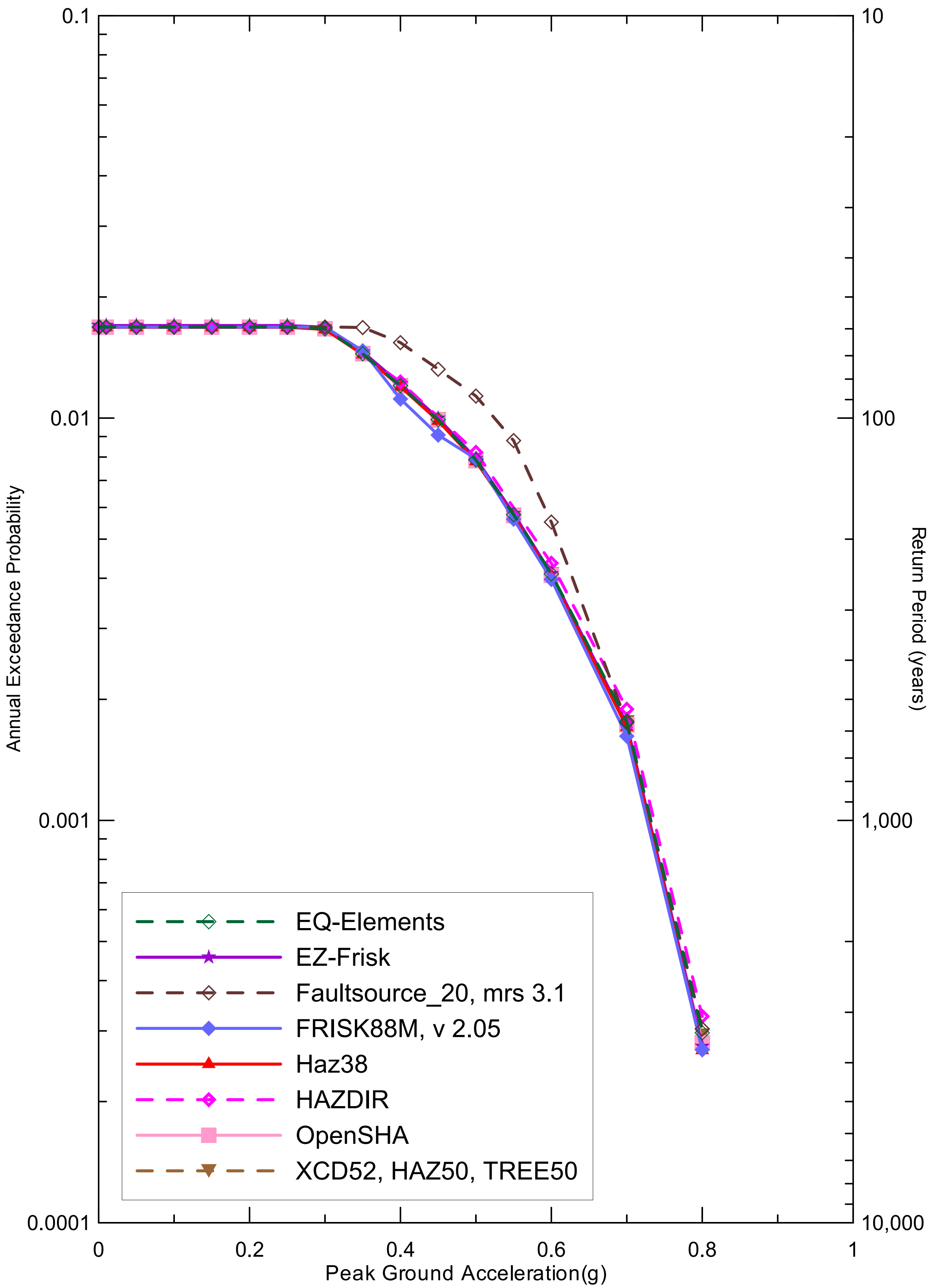
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 3	Figure 3.86



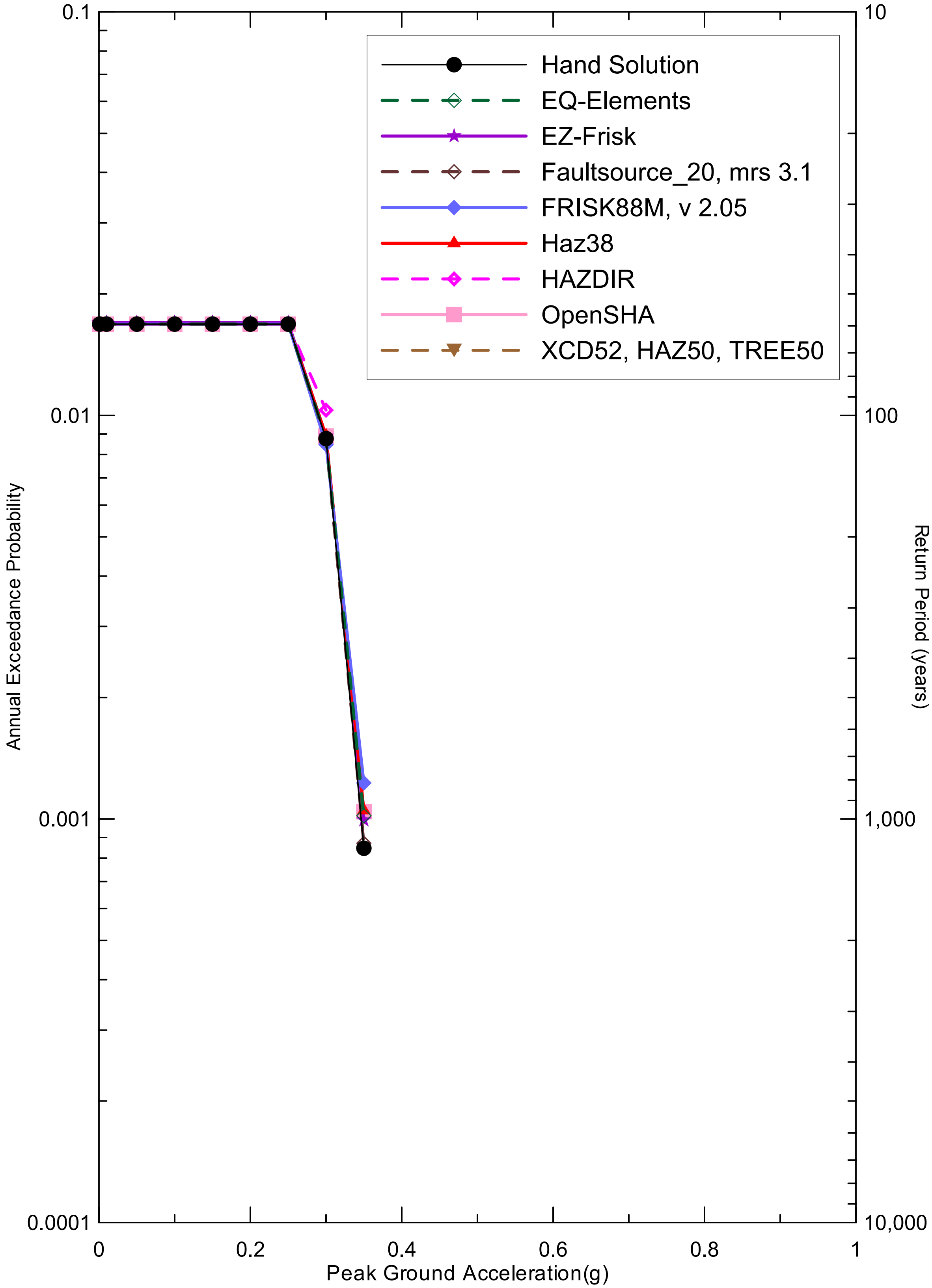
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 4	Figure 3.87



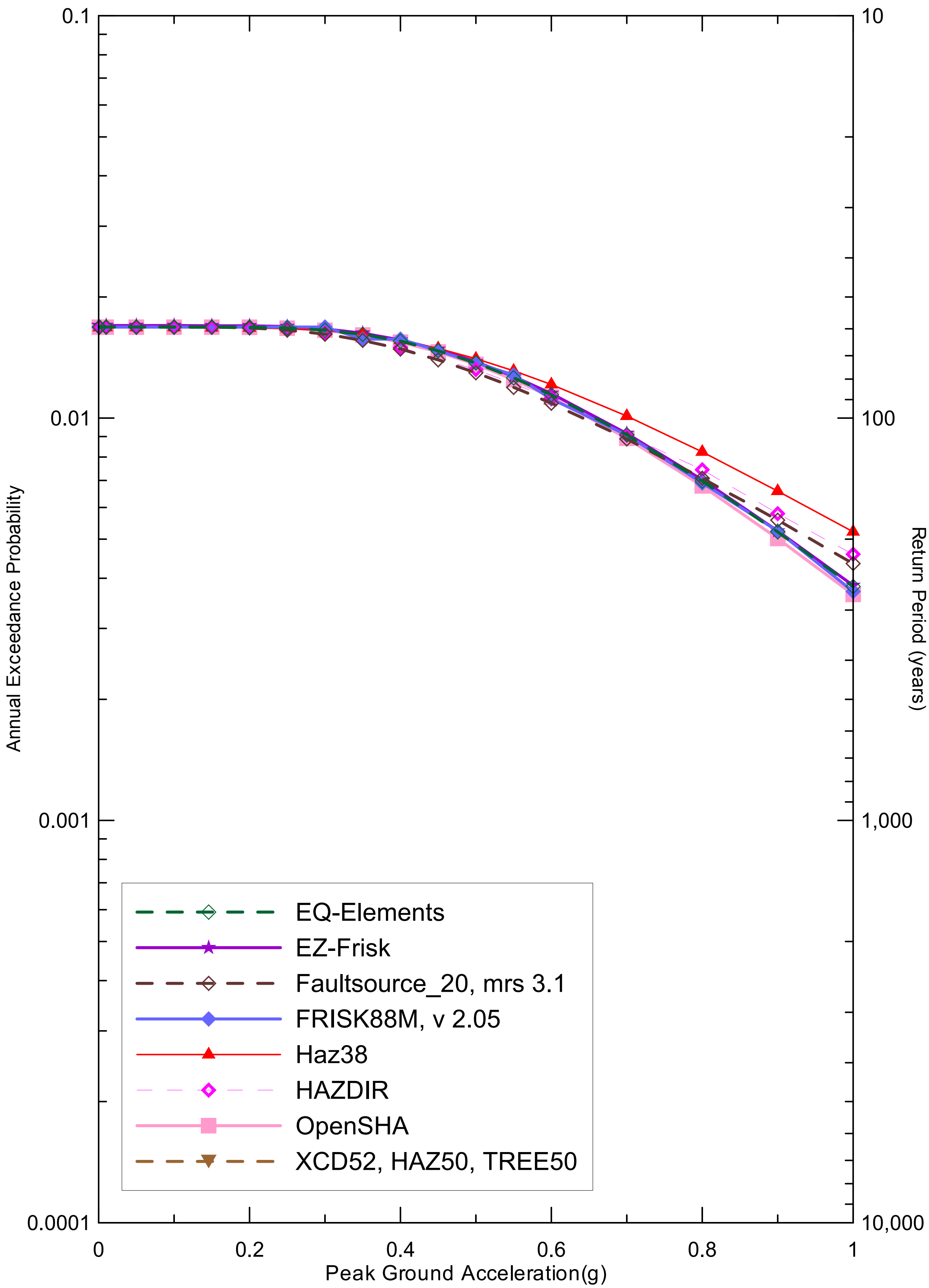
PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 5	Figure 3.88



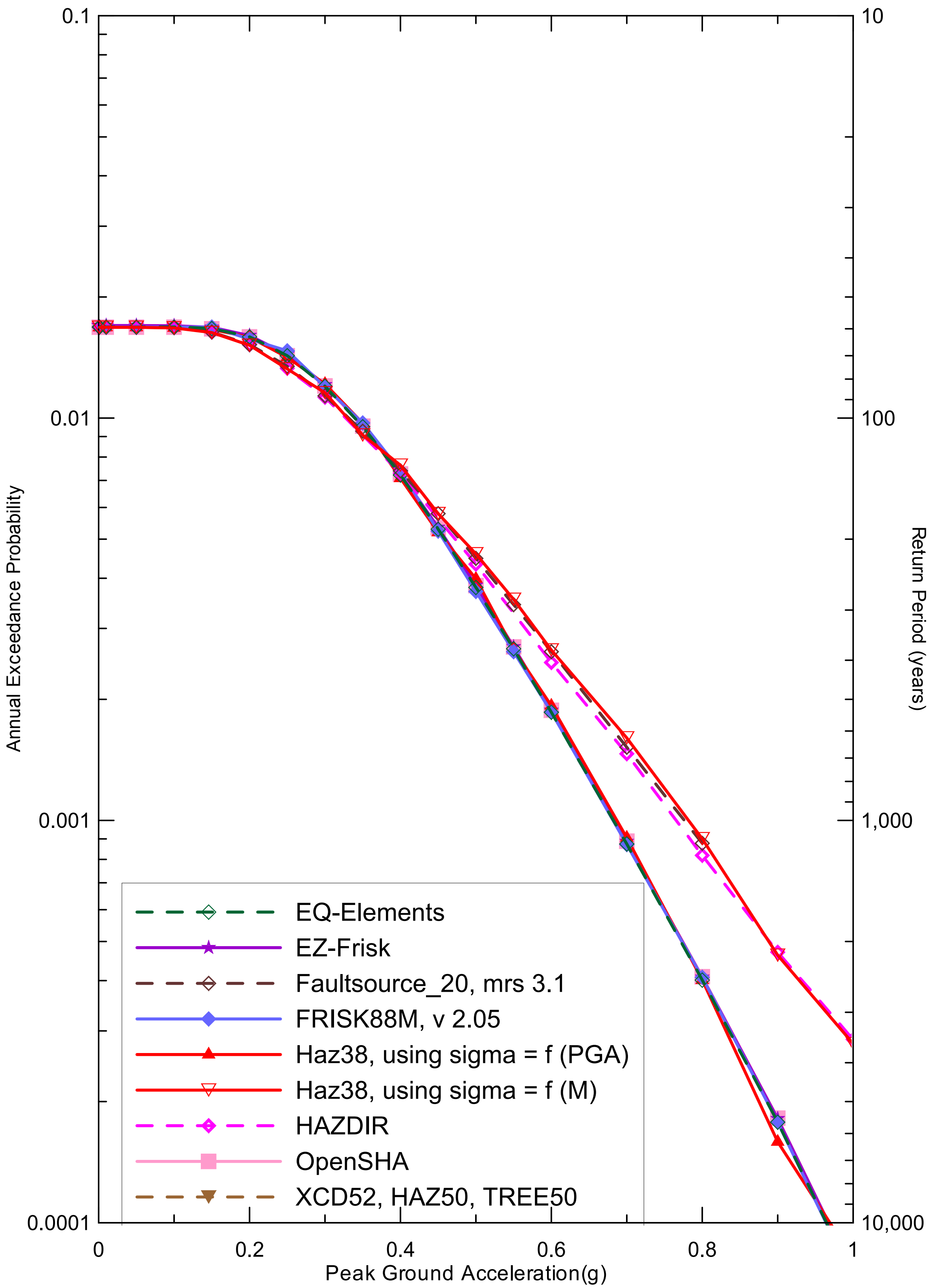
PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 6	Figure 3.89



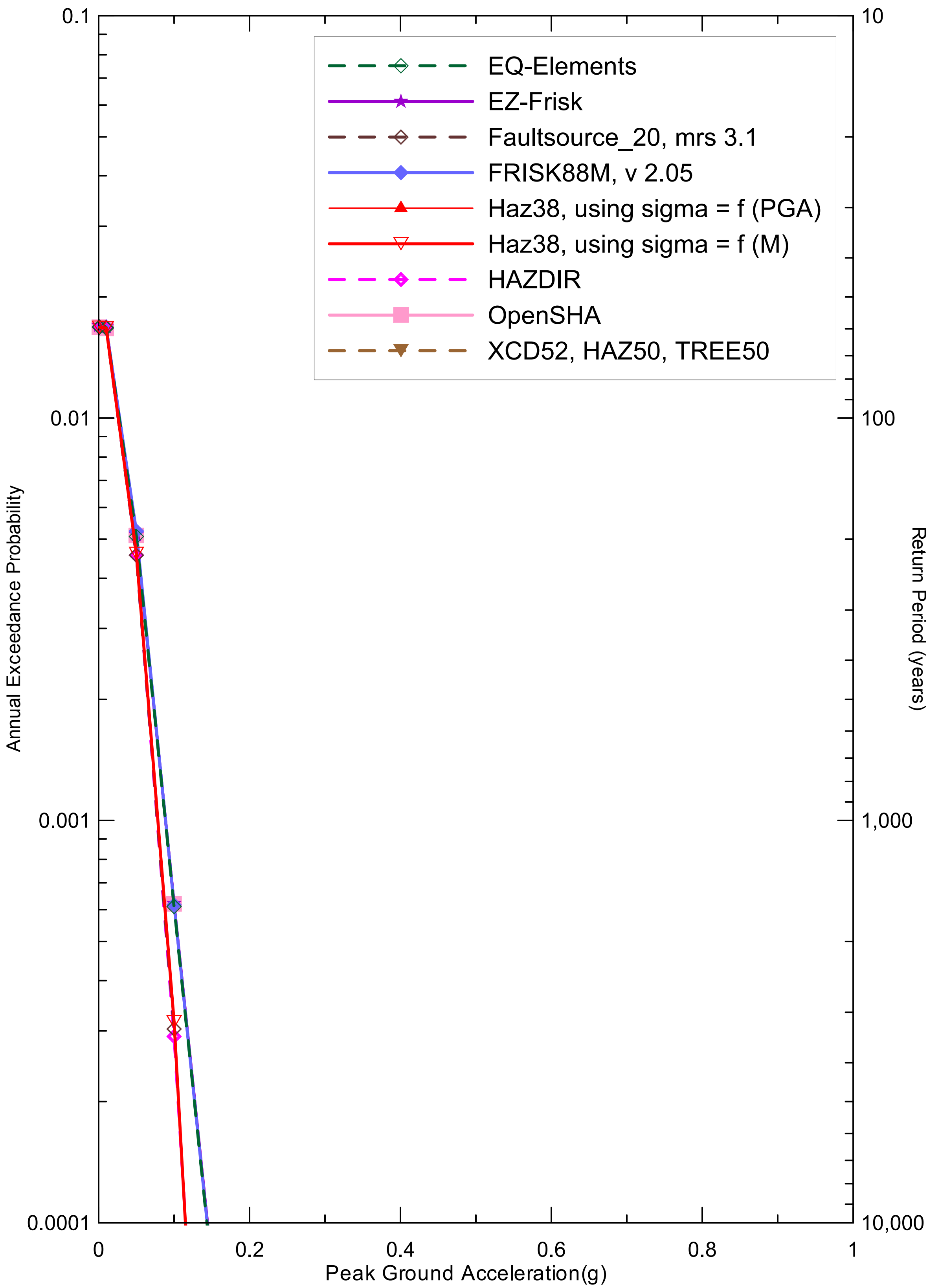
PEER PSHA VERIFICATION	TEST SET 1, CASE 9b, SITE 7	Figure 3.90



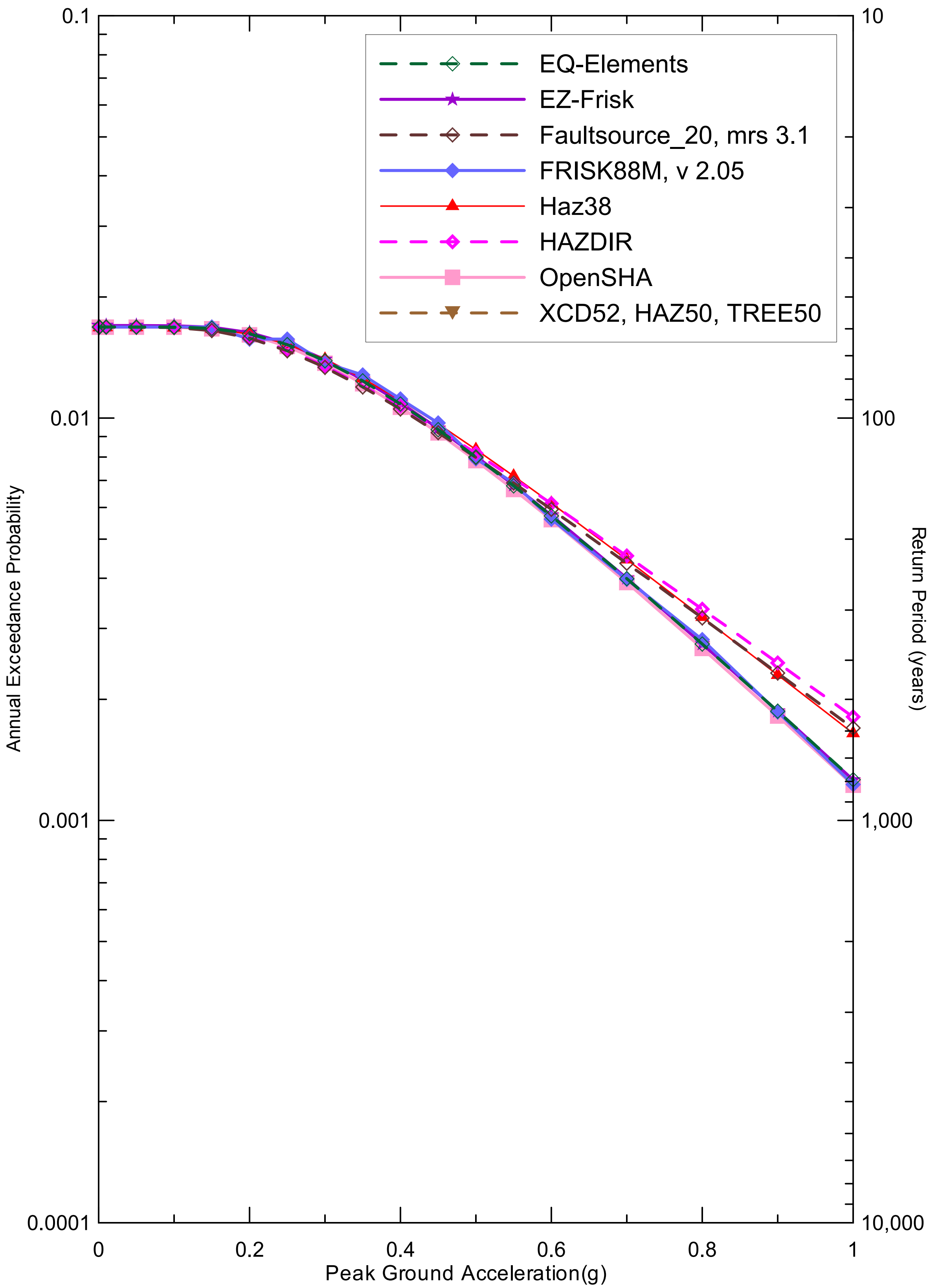
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 1	Figure 3.91



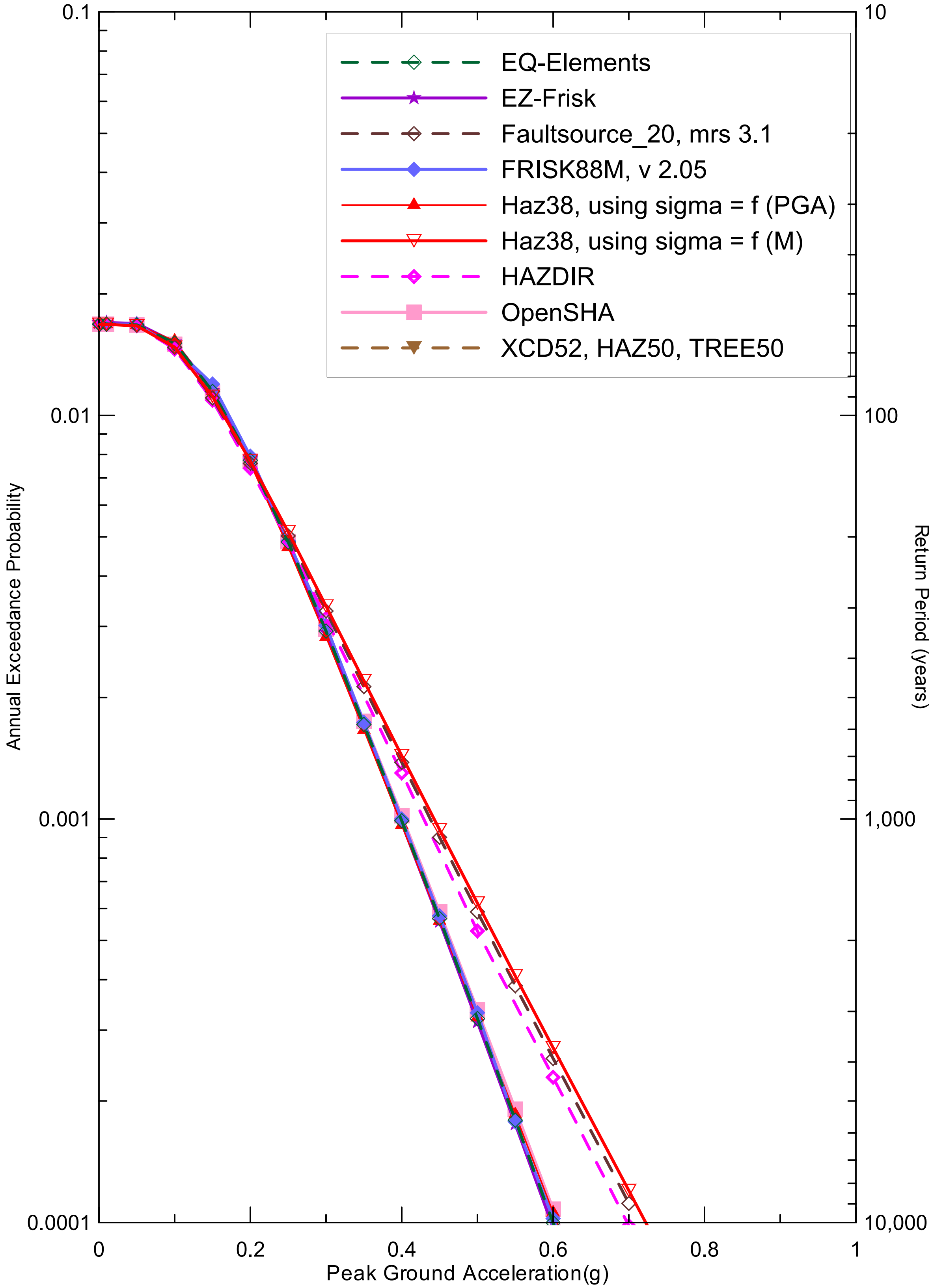
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 2	Figure 3.92



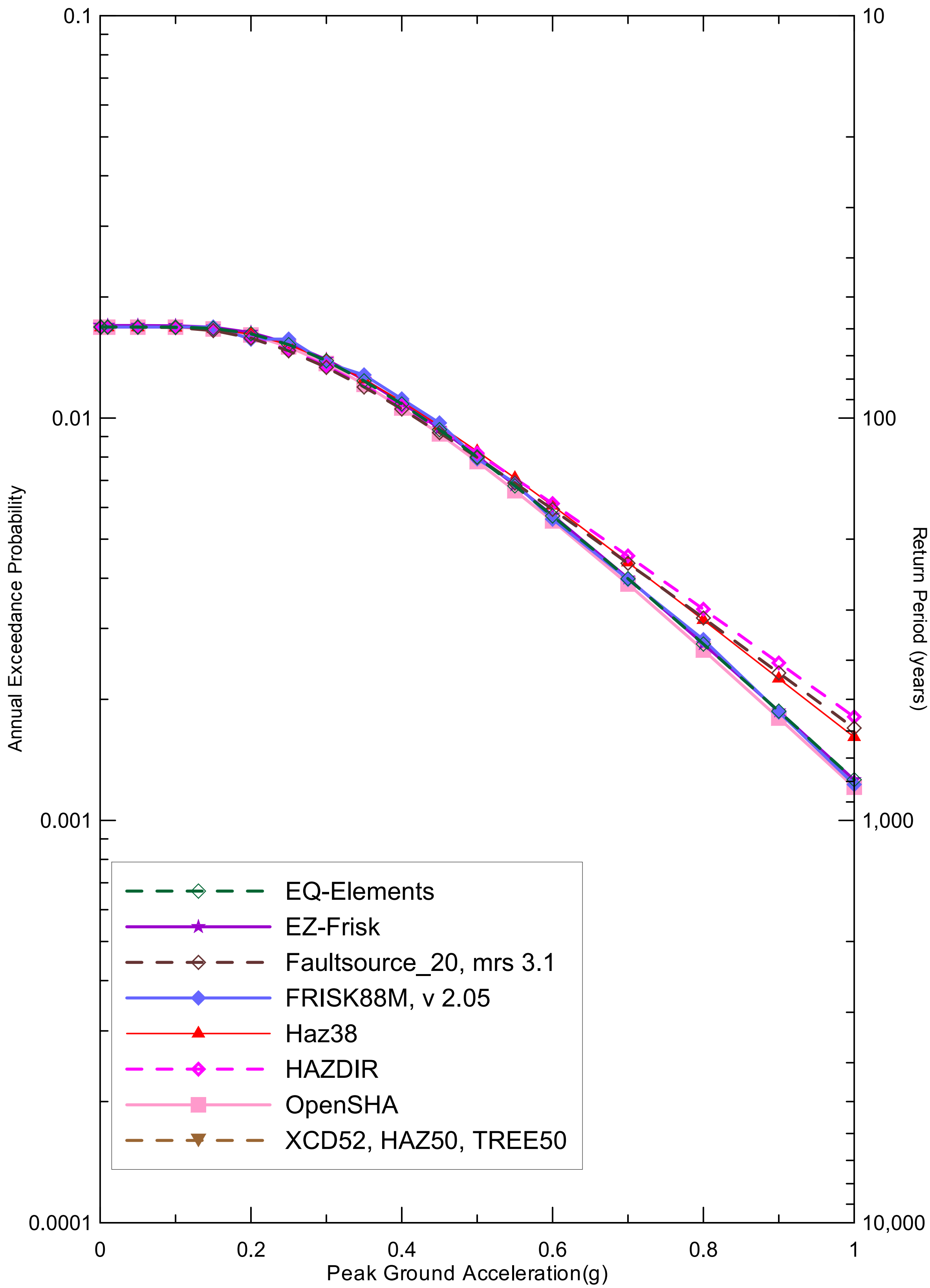
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 3	Figure 3.93



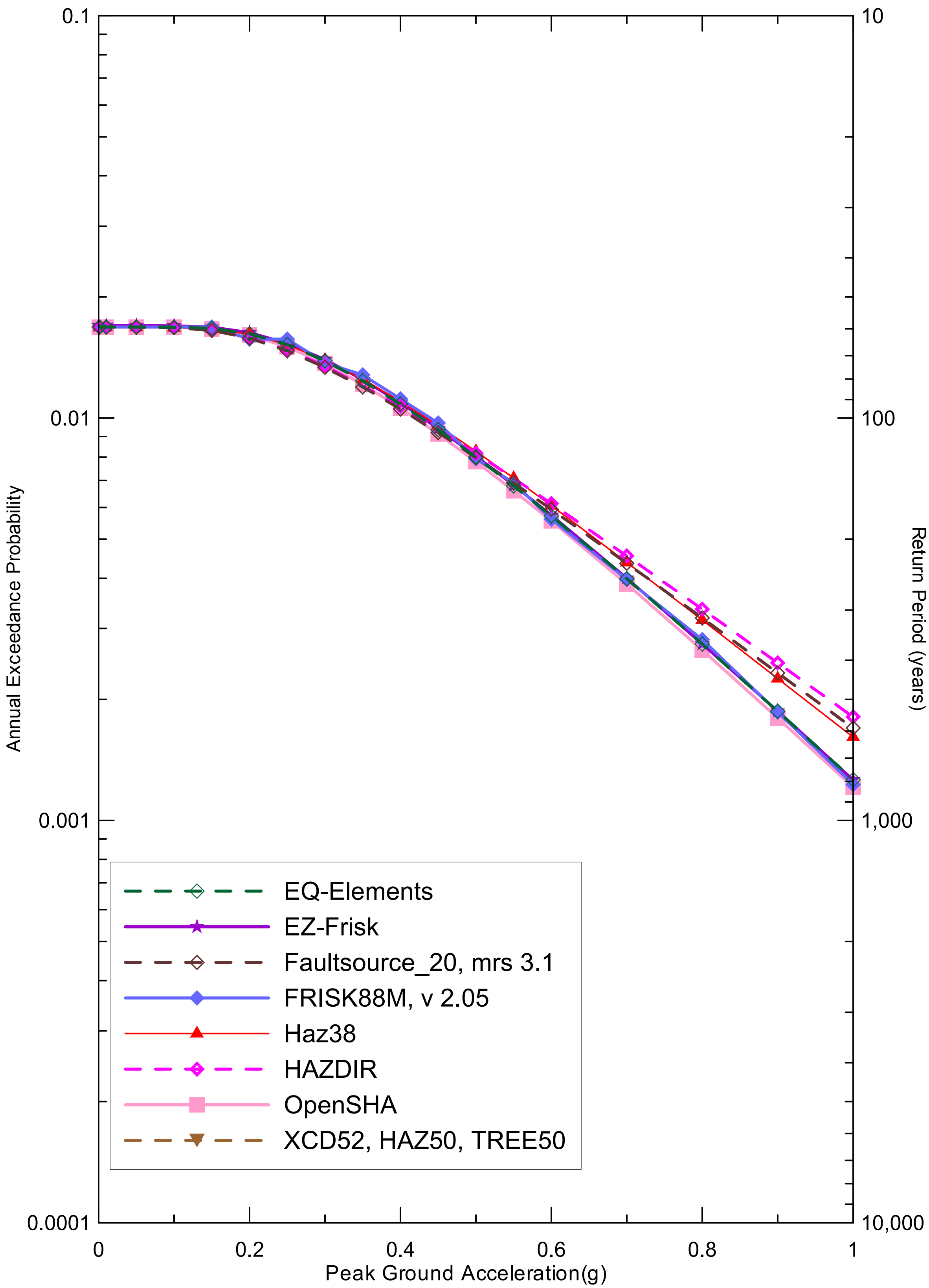
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 4	Figure 3.94



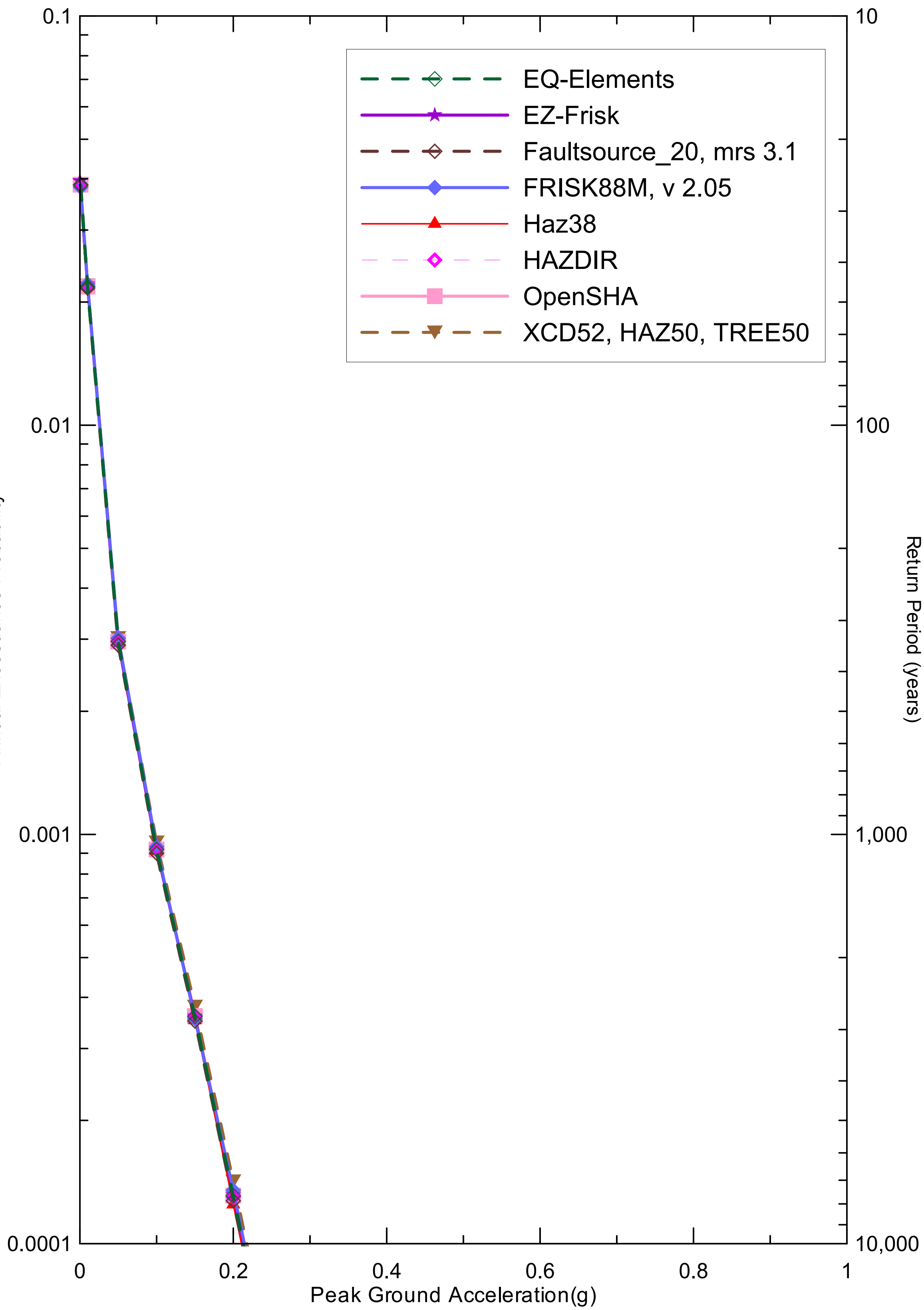
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 5	Figure 3.95



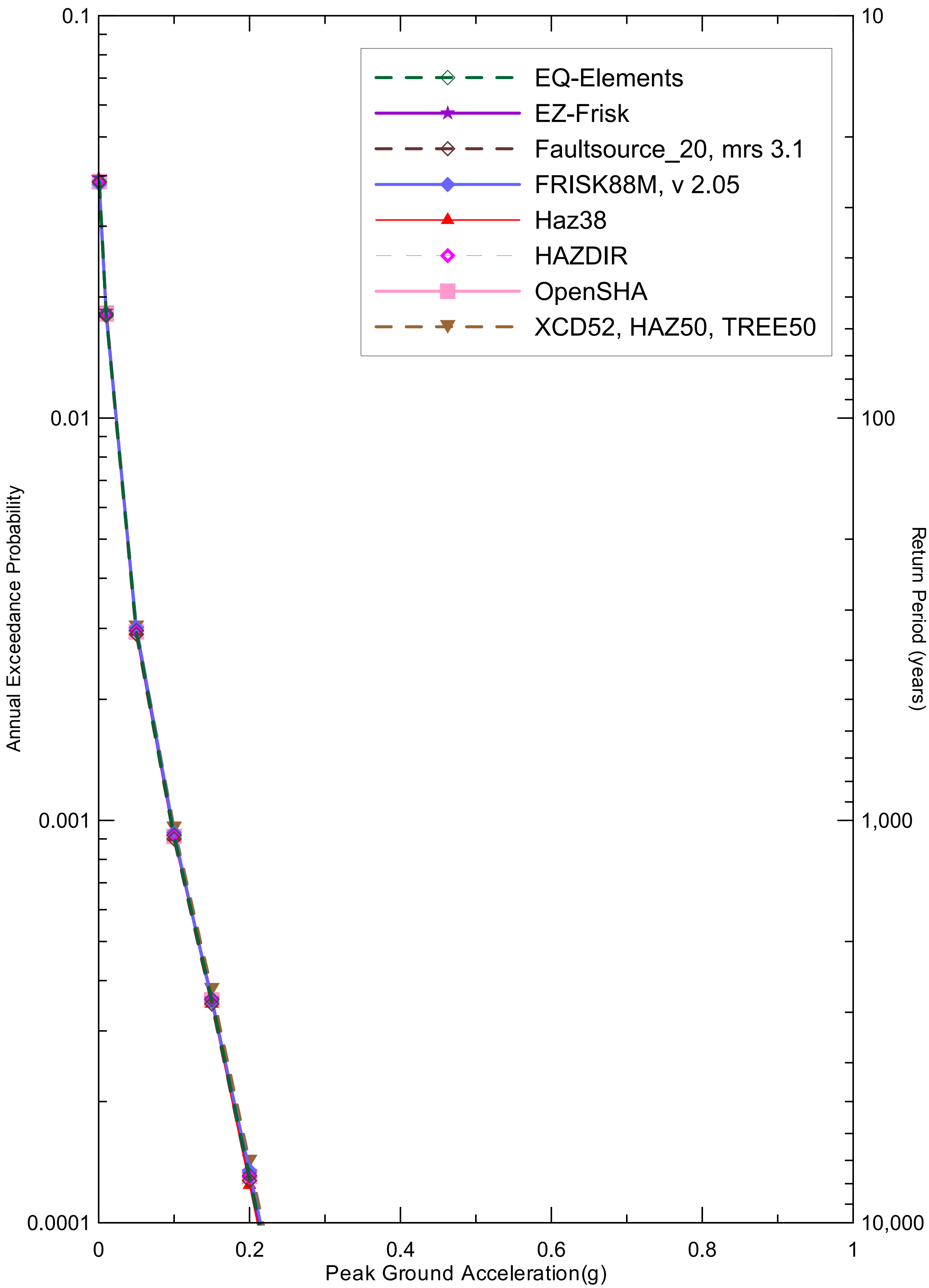
	PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 6	Figure 3.96



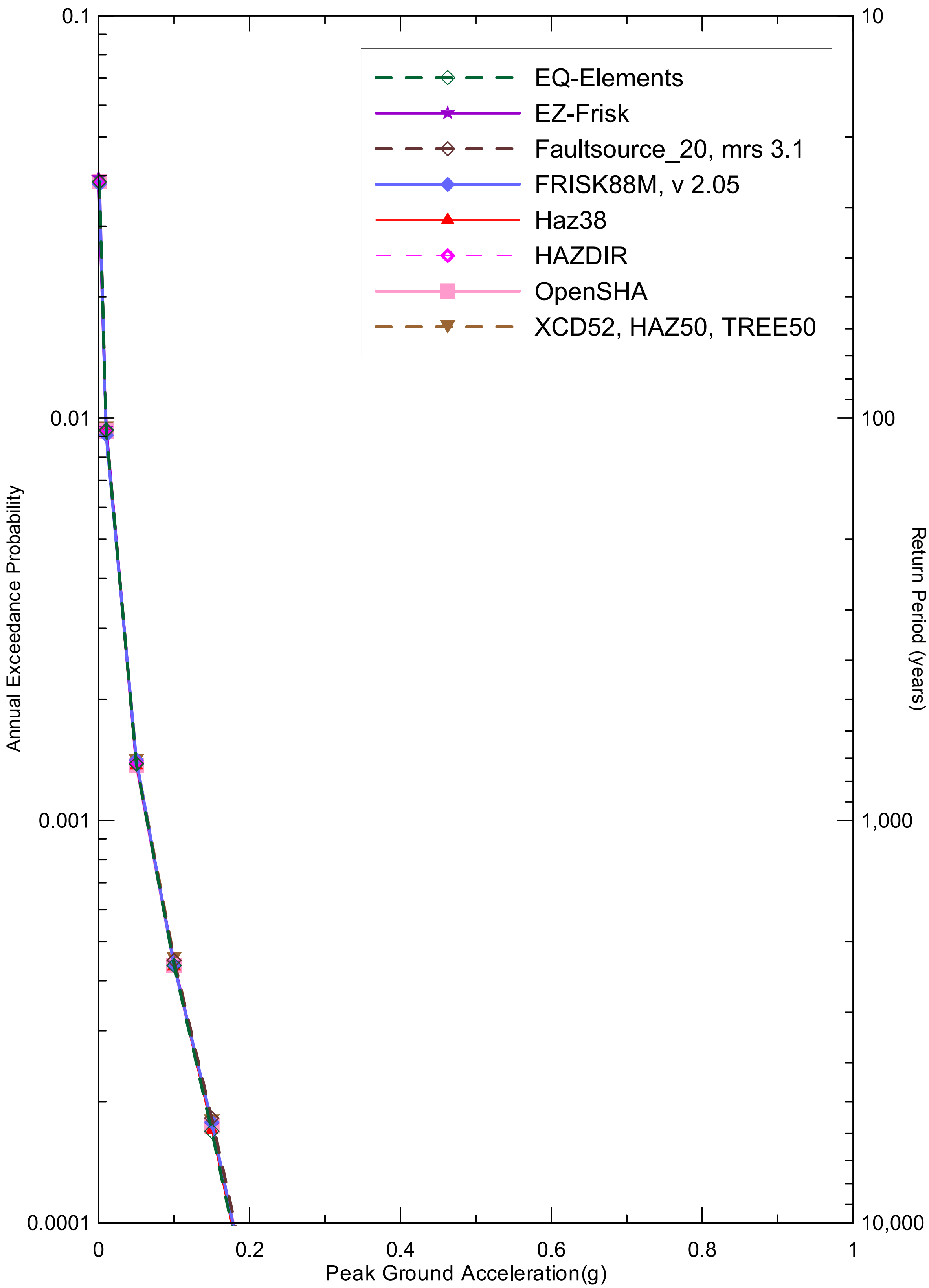
PEER PSHA VERIFICATION	TEST SET 1, CASE 9c, SITE 7	Figure 3.97



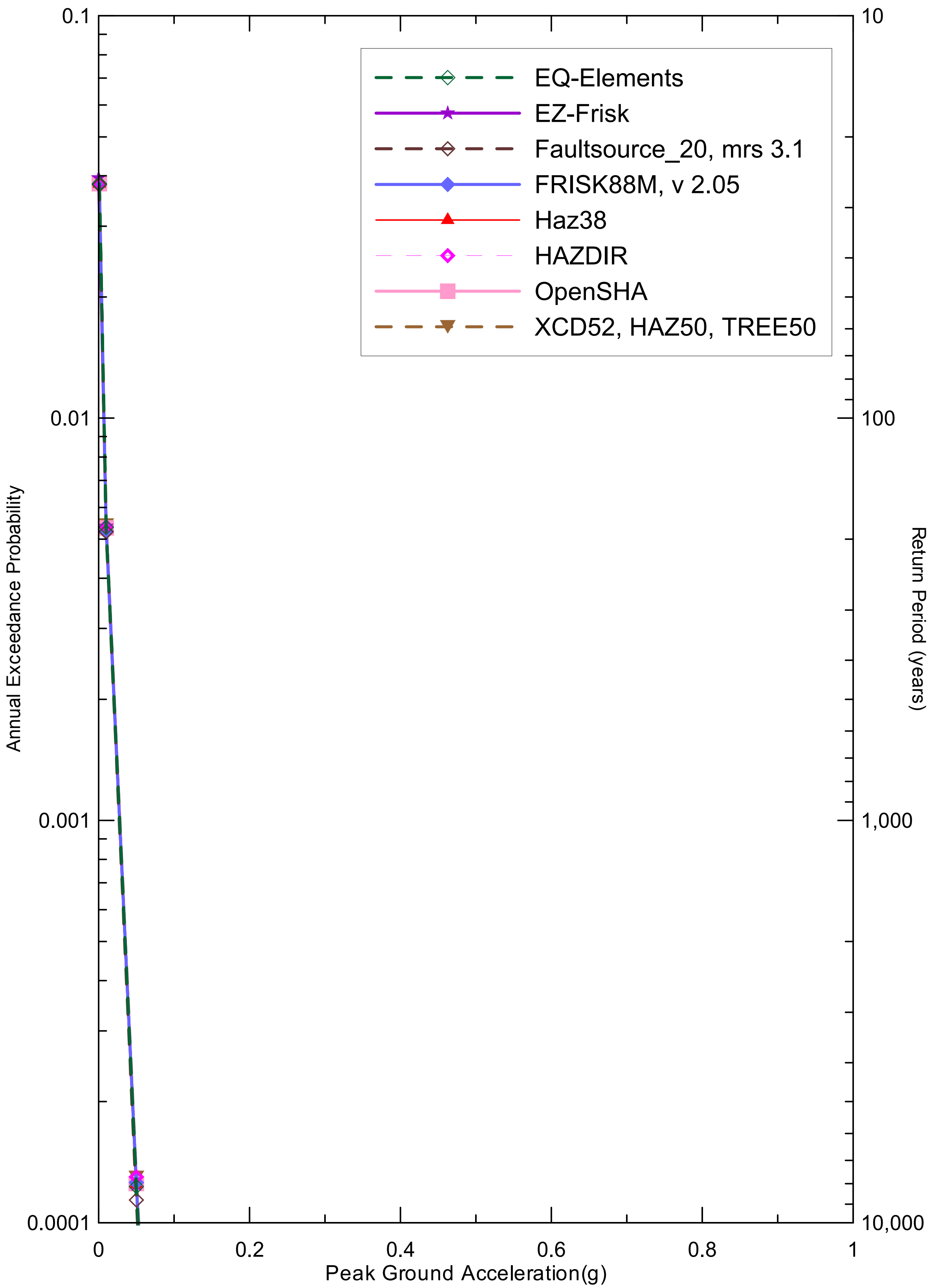
	PEER PSHA VERIFICATION	TEST SET 1, CASE 10, SITE 1	Figure 3.98



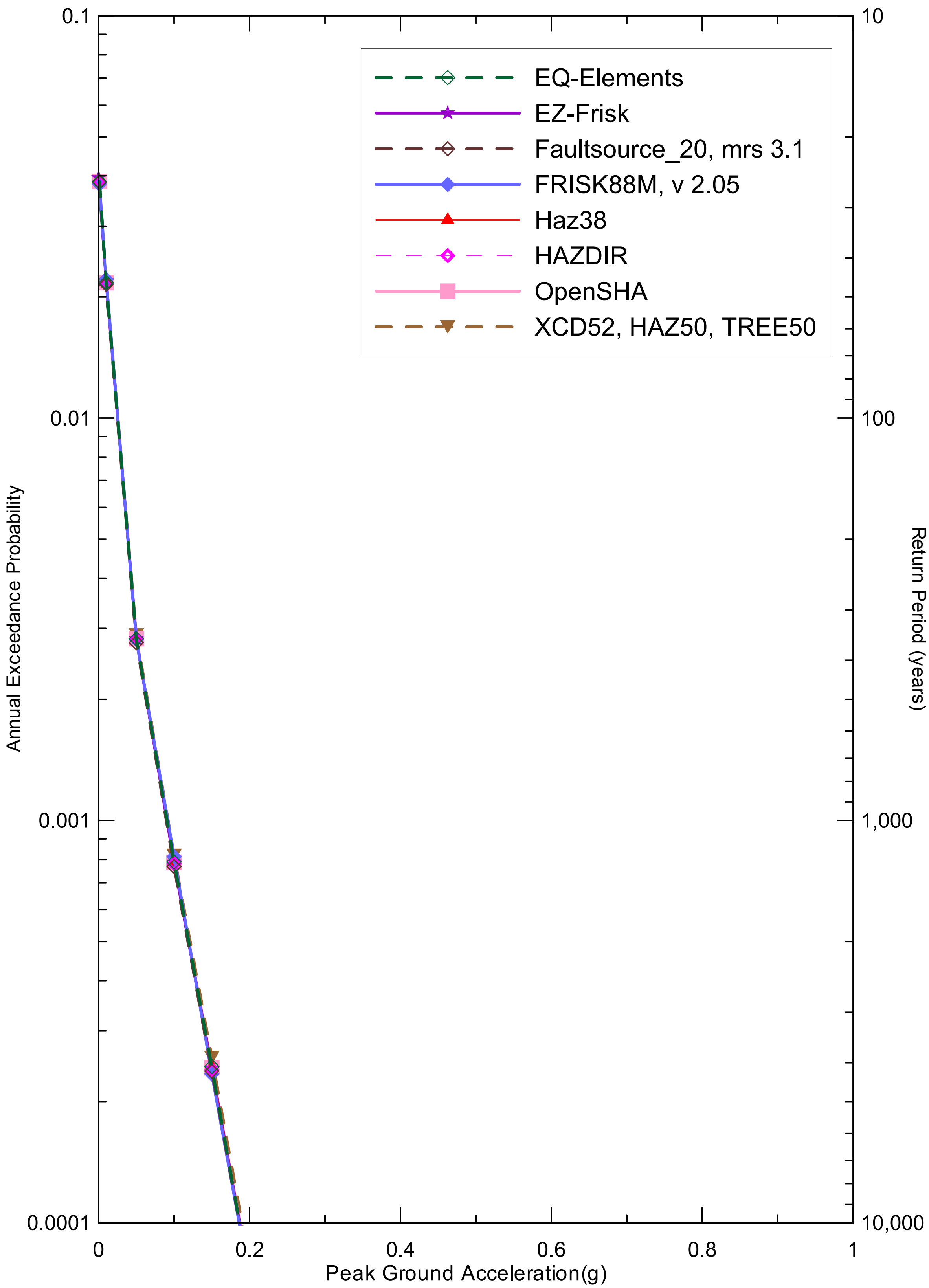
	PEER PSHA VERIFICATION	TEST SET 1, CASE 10, SITE 2	Figure 3.99



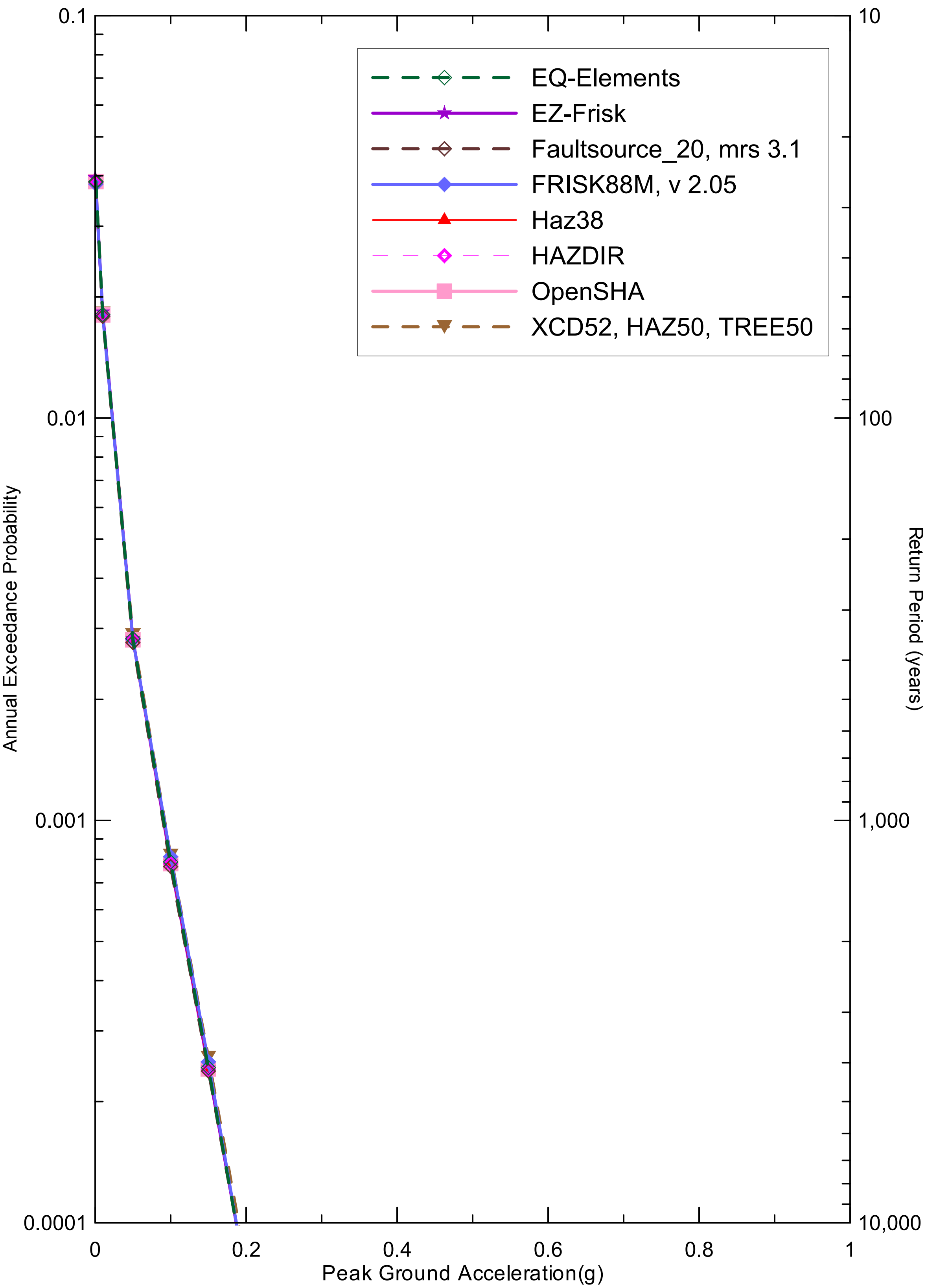
	PEER PSHA VERIFICATION	TEST SET 1, CASE 10, SITE 3	Figure 3.100



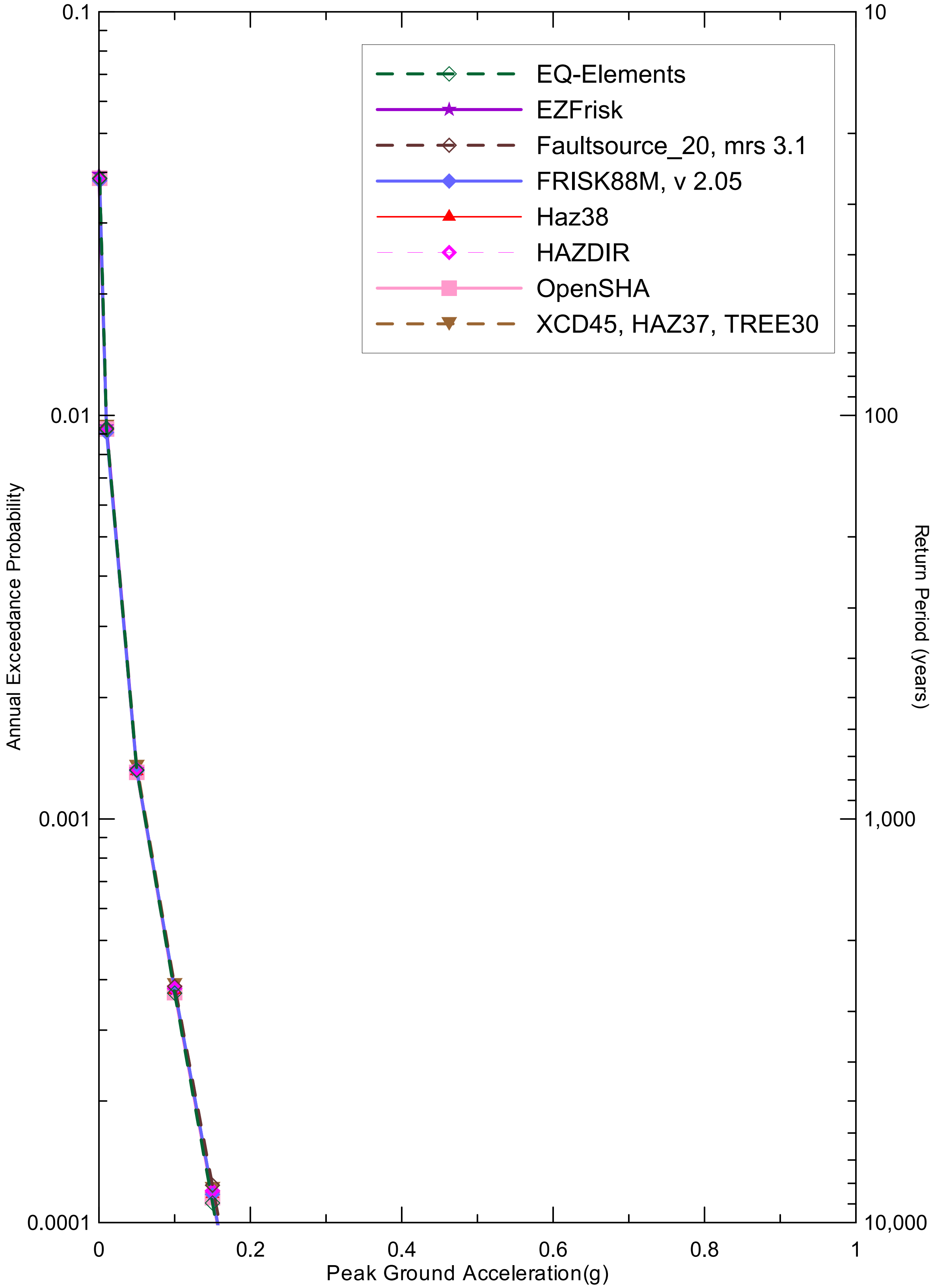
	PEER PSHA VERIFICATION	TEST SET 1, CASE 10, SITE 4	Figure 3.101



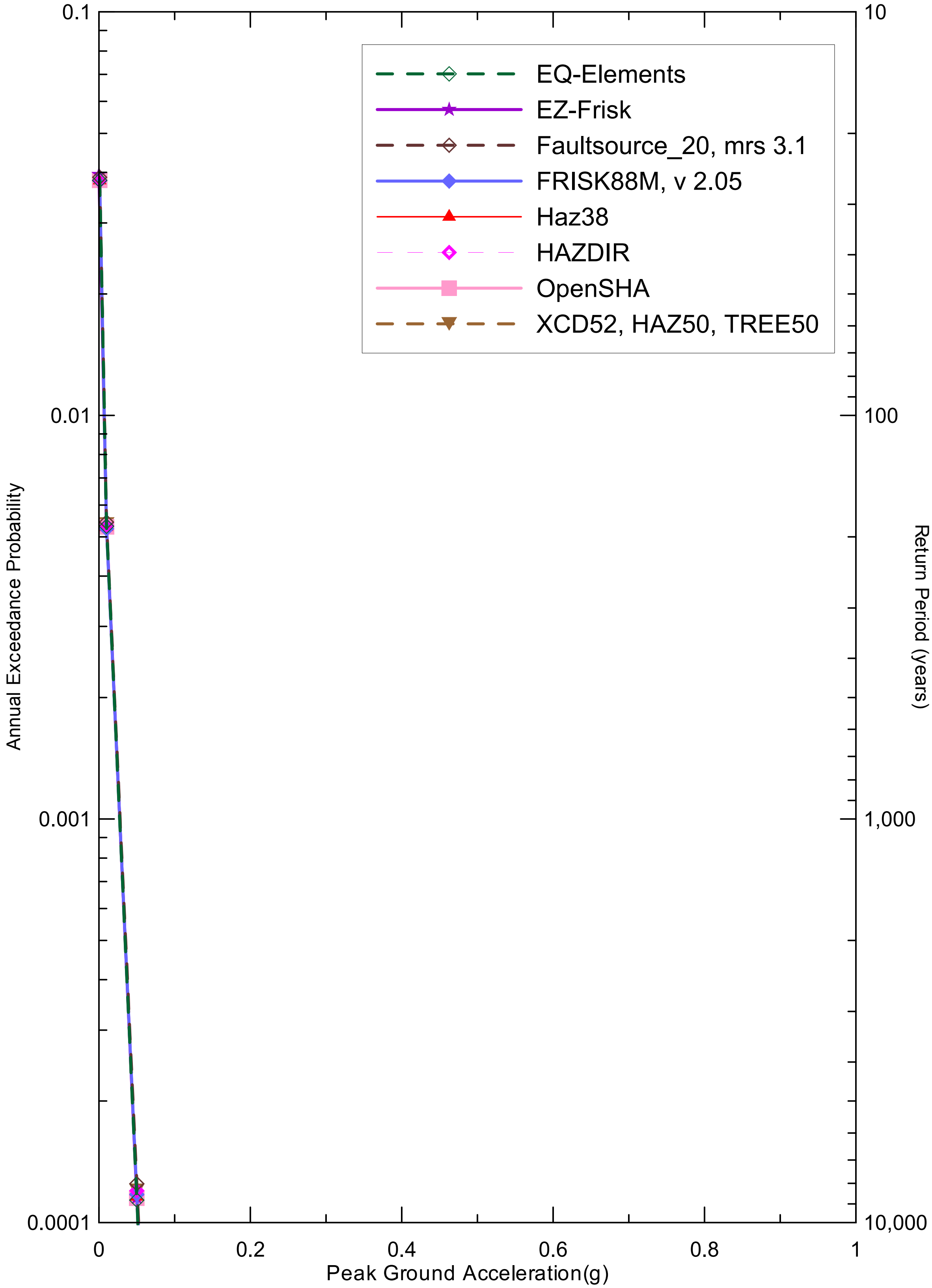
PEER PSHA VERIFICATION	TEST SET 1, CASE 11, SITE 1	Figure 3.102



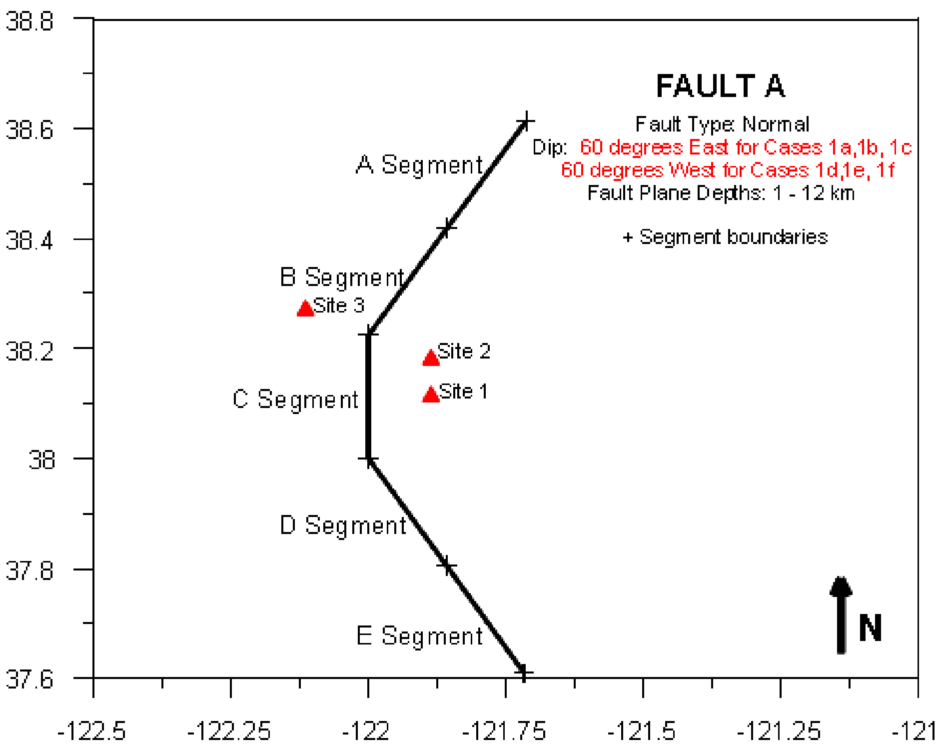
PEER PSHA VERIFICATION	TEST SET 1, CASE 11, SITE 2	Figure 3.103



	PEER PSHA VERIFICATION	TEST SET 1, CASE 11, SITE 3	Figure 3.104

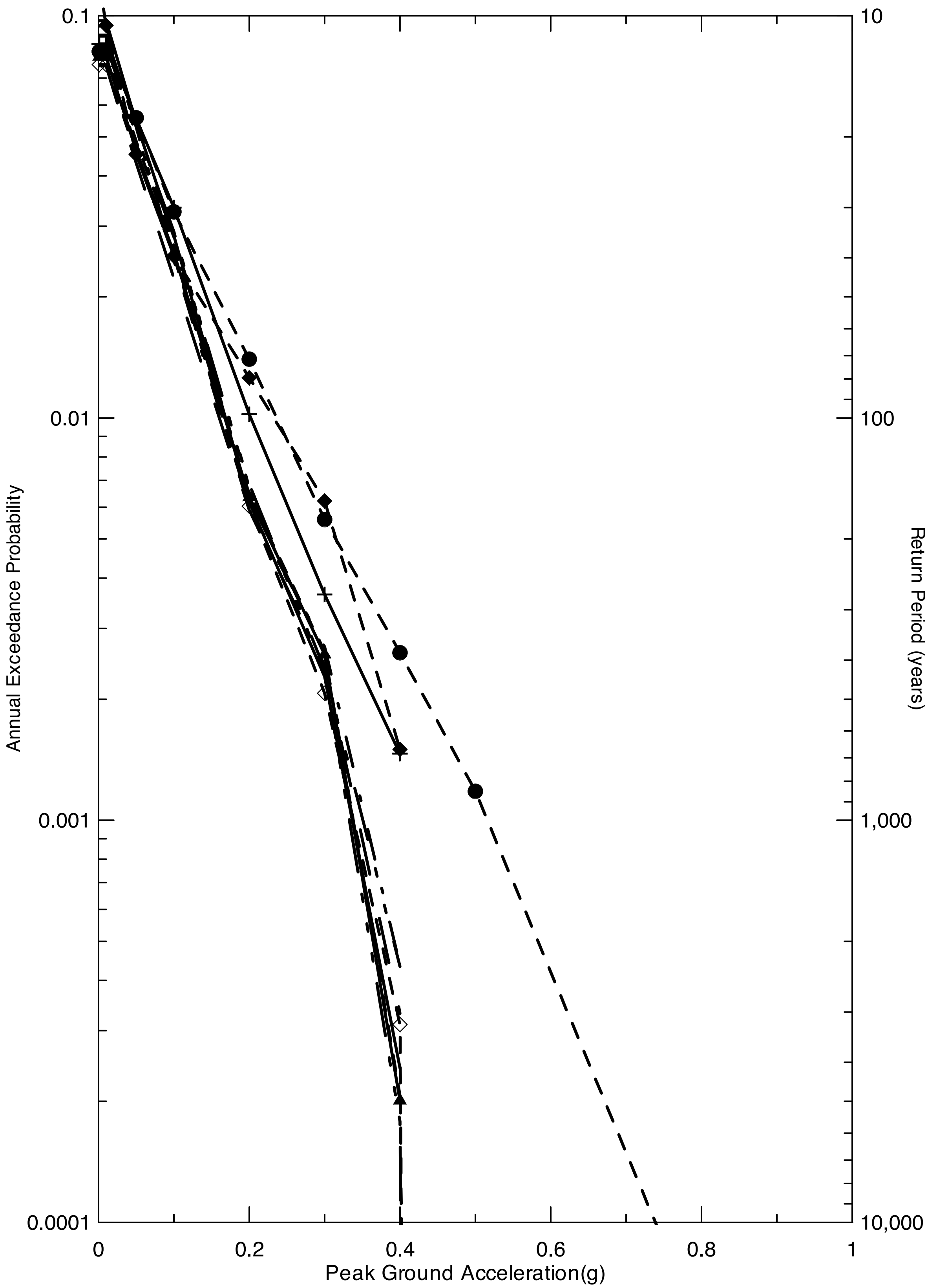


	PEER PSHA VERIFICATION	TEST SET 1, CASE 11, SITE 4	Figure 3.105

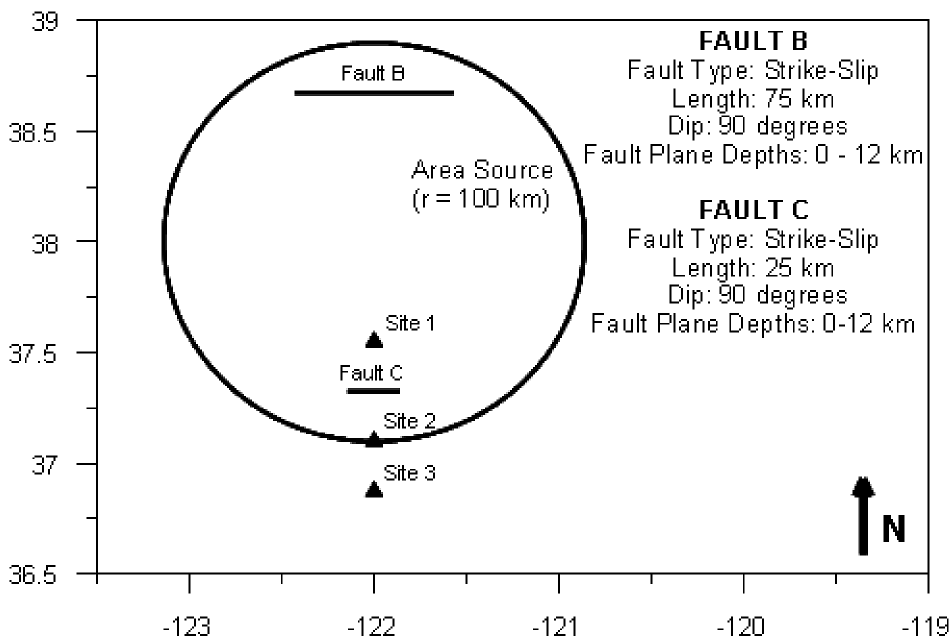


(Coordinates are in Set2_Rev2_Coordinates_Results.xls)

	PEER PSHA VERIFICATION	FAULT AND SITE GEOMETRY FOR CASES 1 AND 5	Figure 3.106

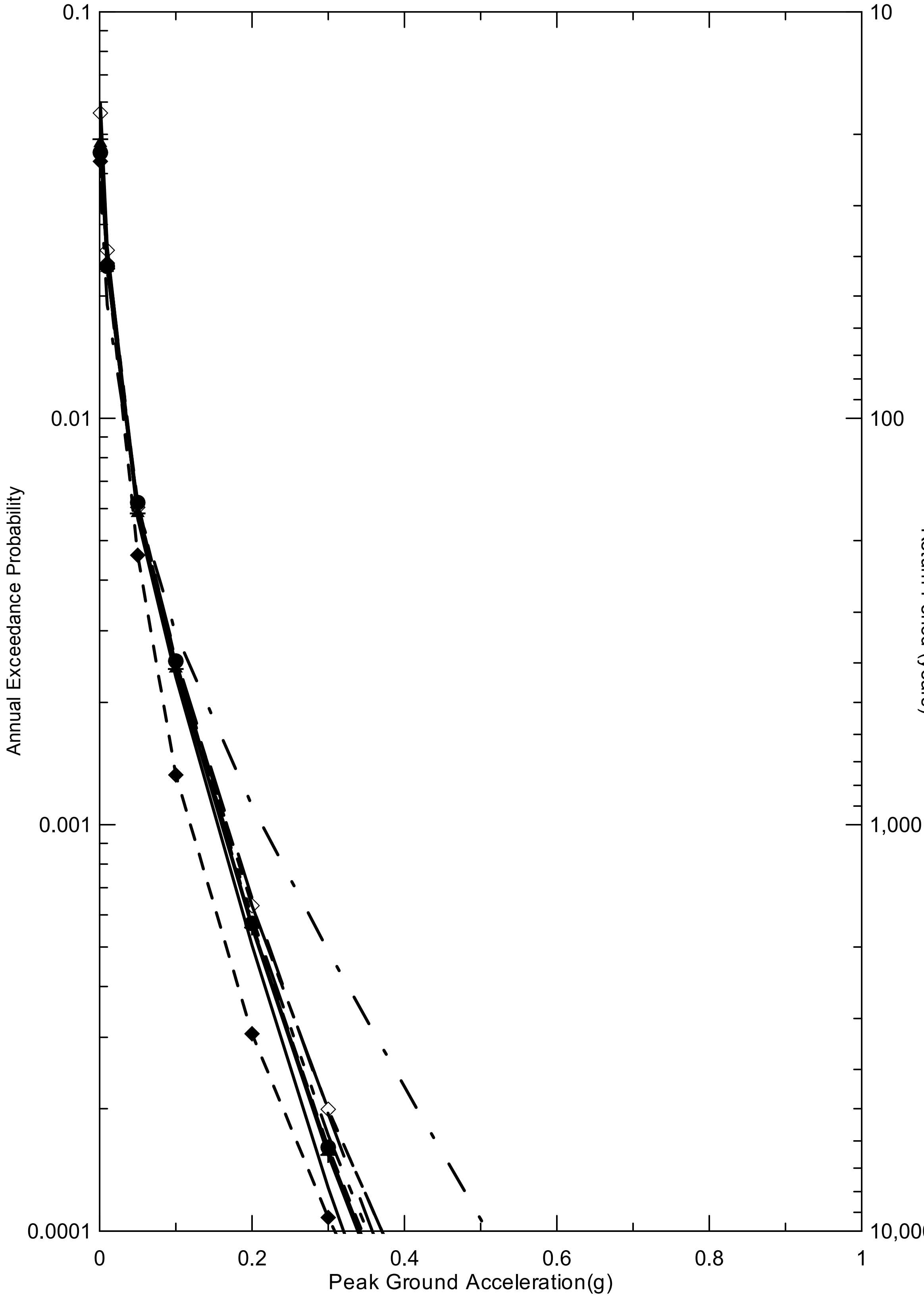


	PEER PSHA VERIFICATION	TEST SET 2, CASE 1, SITE 1 EARLY RESULTS	Figure 3.107

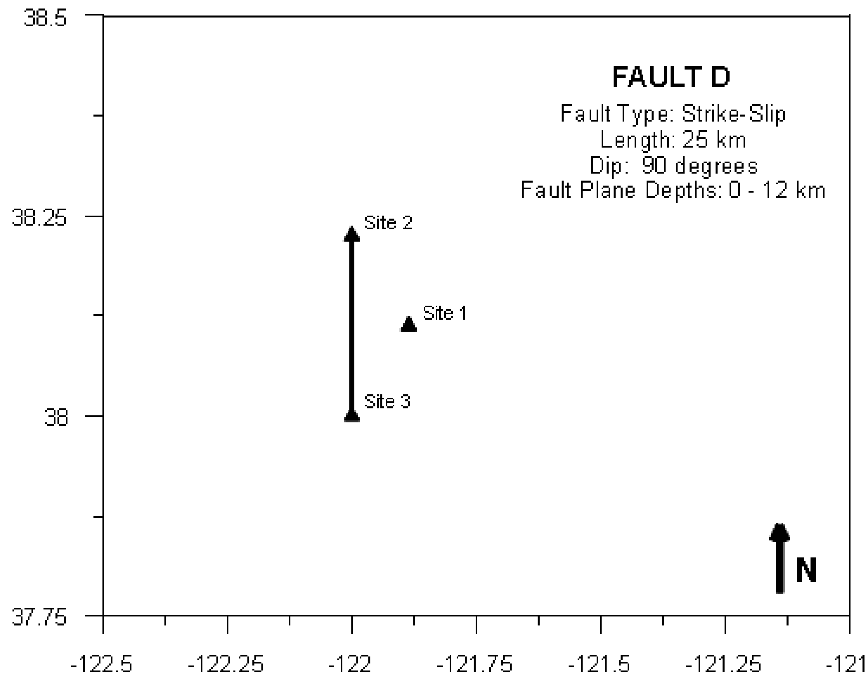


(Coordinates are in Set2_Rev2_Coordinates_Results.xls)

	PEER PSHA VERIFICATION	FAULT AND SITE GEOMETRY FOR CASE 2	Figure 3.108

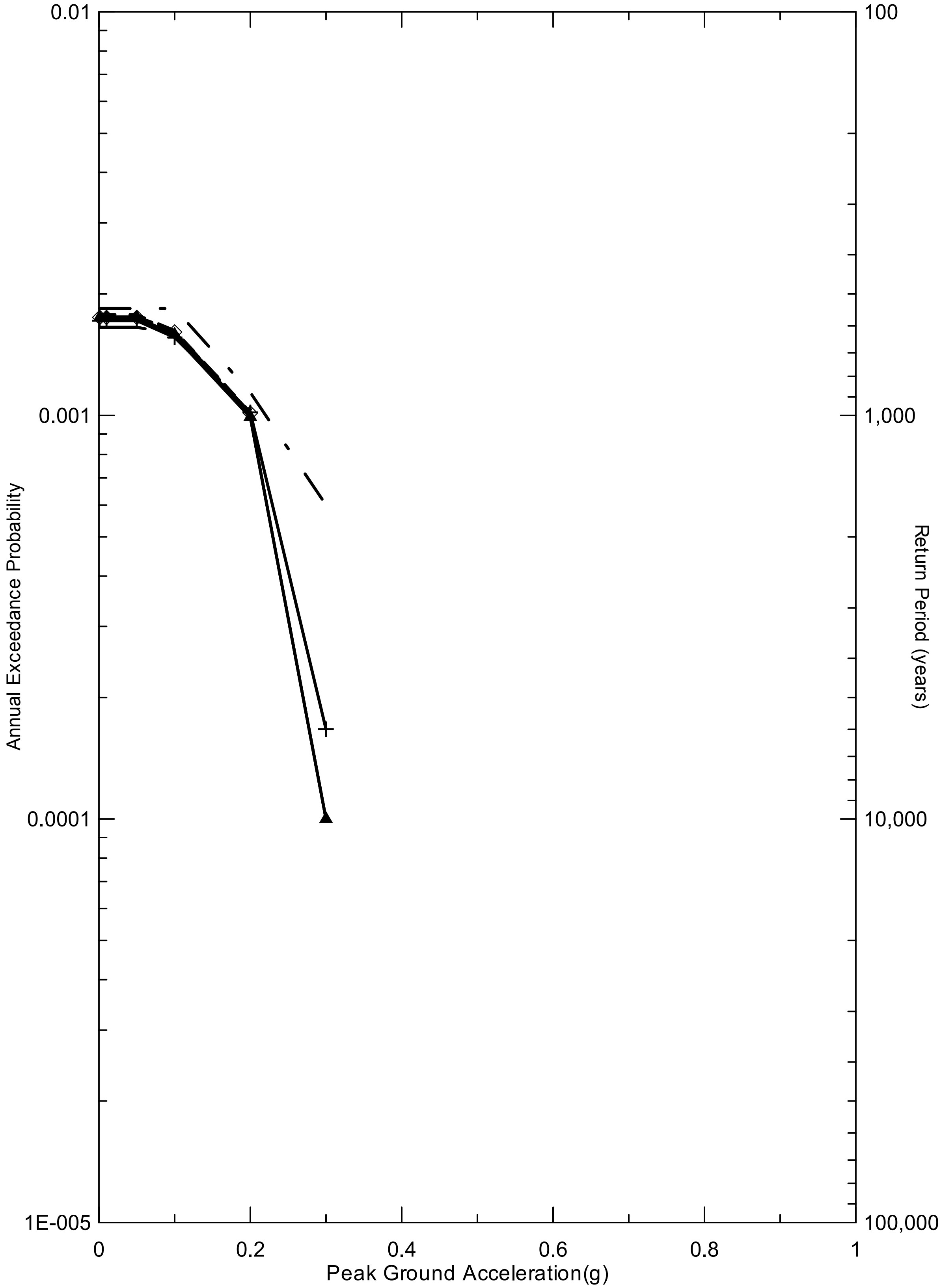


	PEER PSHA VERIFICATION	TEST SET 2, CASE 2, SITE 1 EARLY RESULTS	Figure 3.109

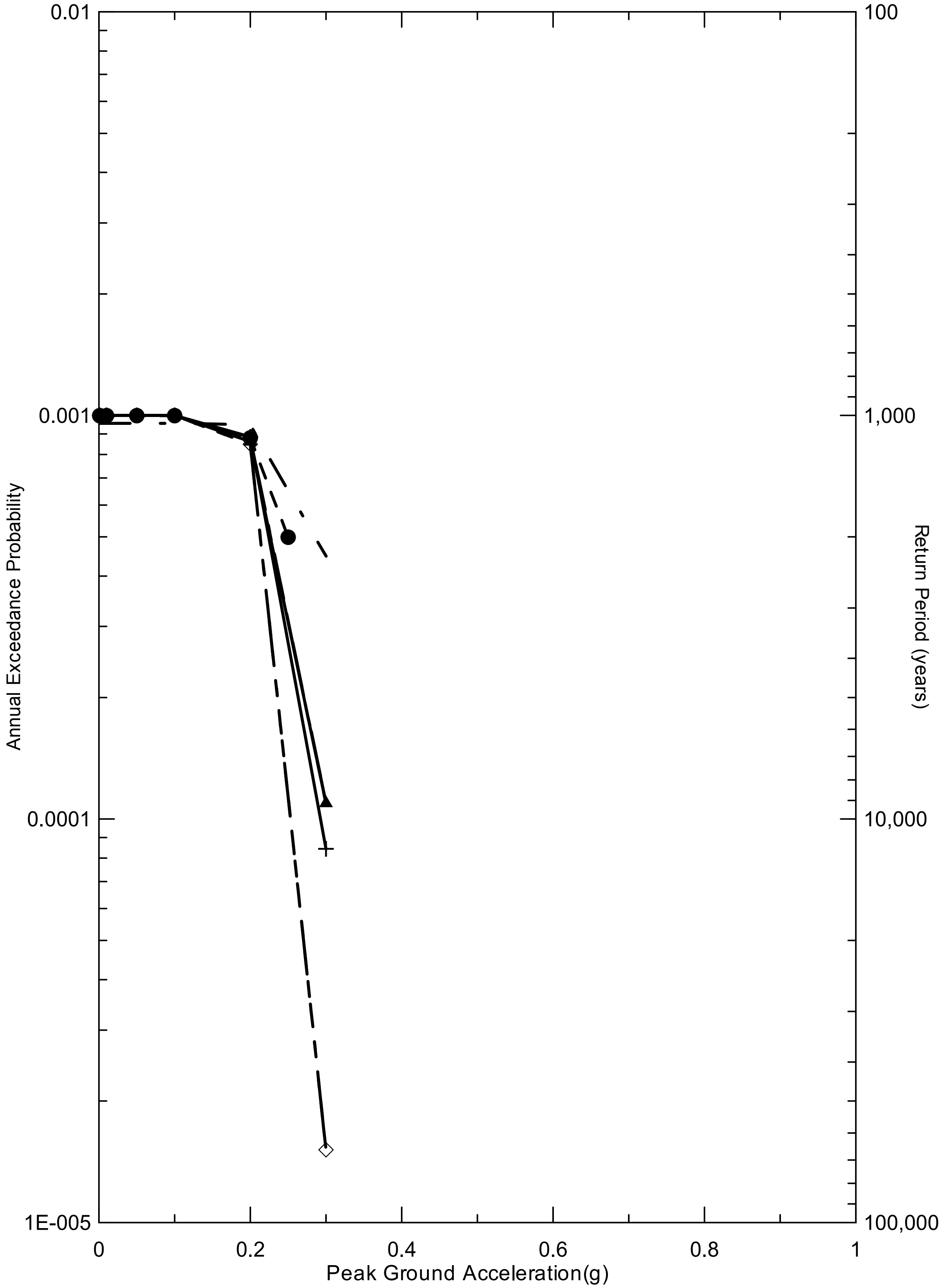


(Coordinates are in Set2_Rev2_Coordinates_Results.xls)

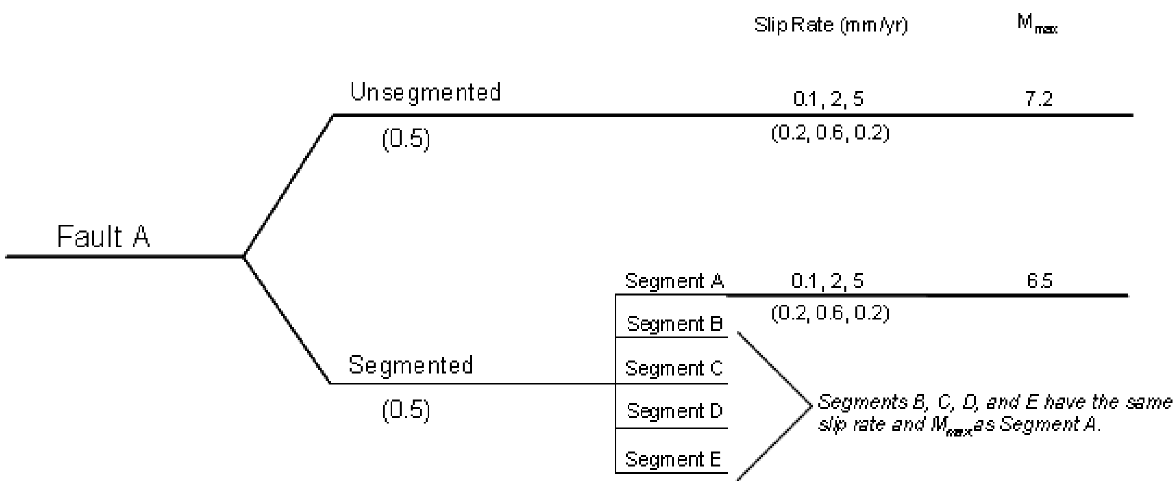
	PEER PSHA VERIFICATION	FAULT AND SITE GEOMETRY FOR CASES 3 AND 4	Figure 3.110



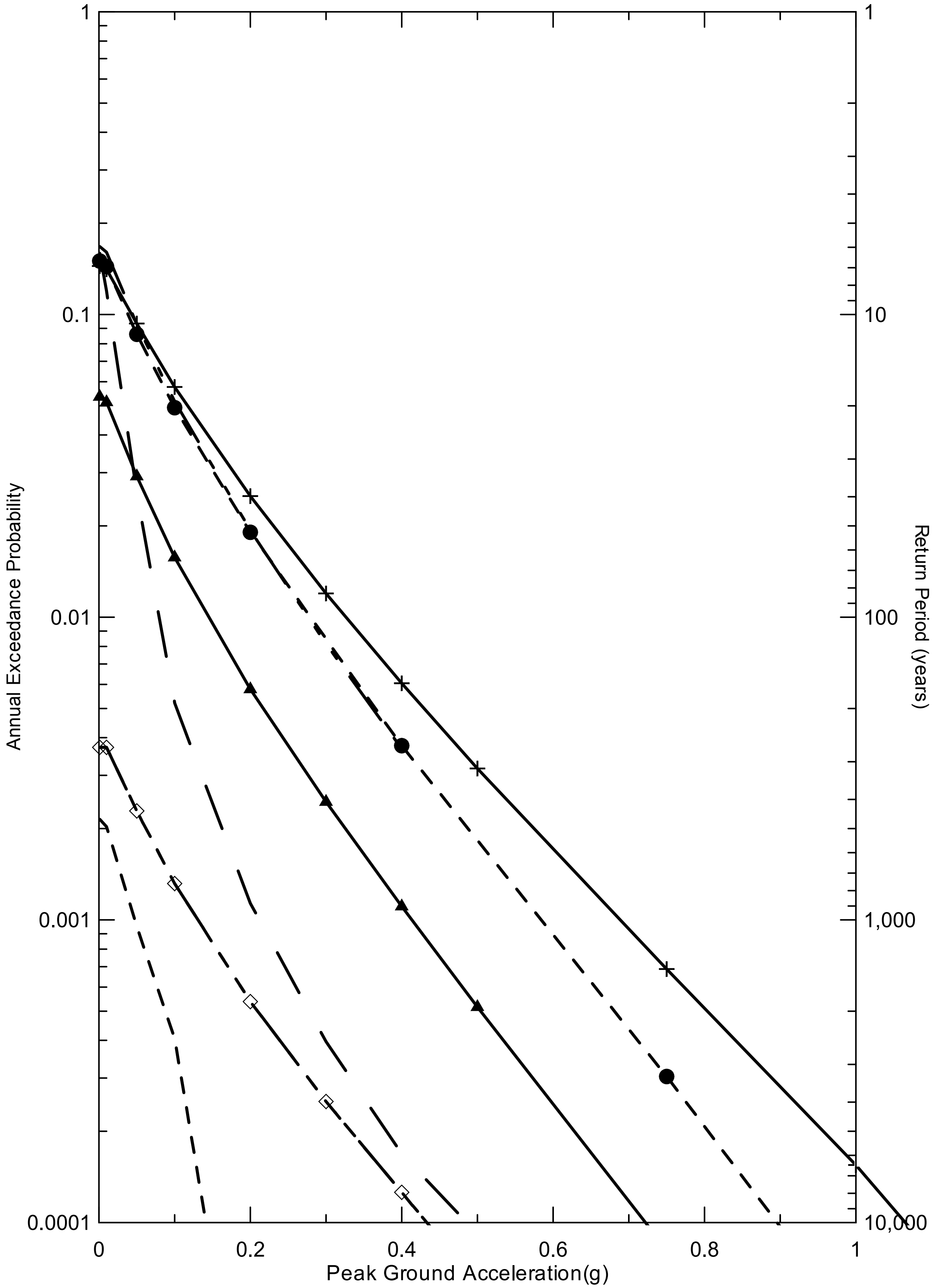
	PEER PSHA VERIFICATION	TEST SET 2, CASE 3, SITE 1 EARLY RESULTS	Figure 3.111



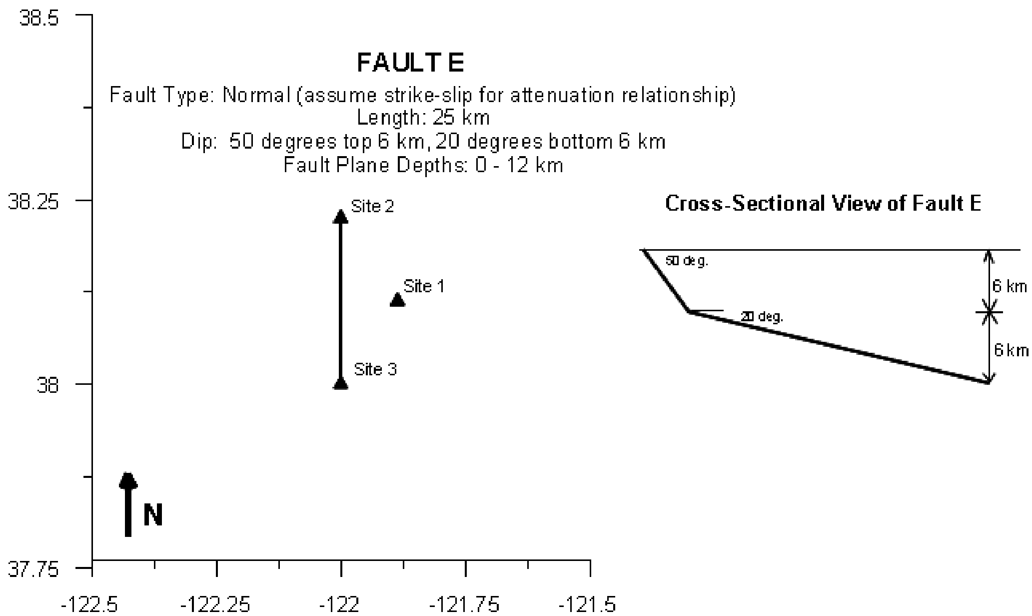
	PEER PSHA VERIFICATION	TEST SET 2, CASE 4, SITE 1 EARLY RESULTS	Figure 3.112



	PEER PSHA VERIFICATION	LOGIC TREE FOR CASE 5	Figure 3.113

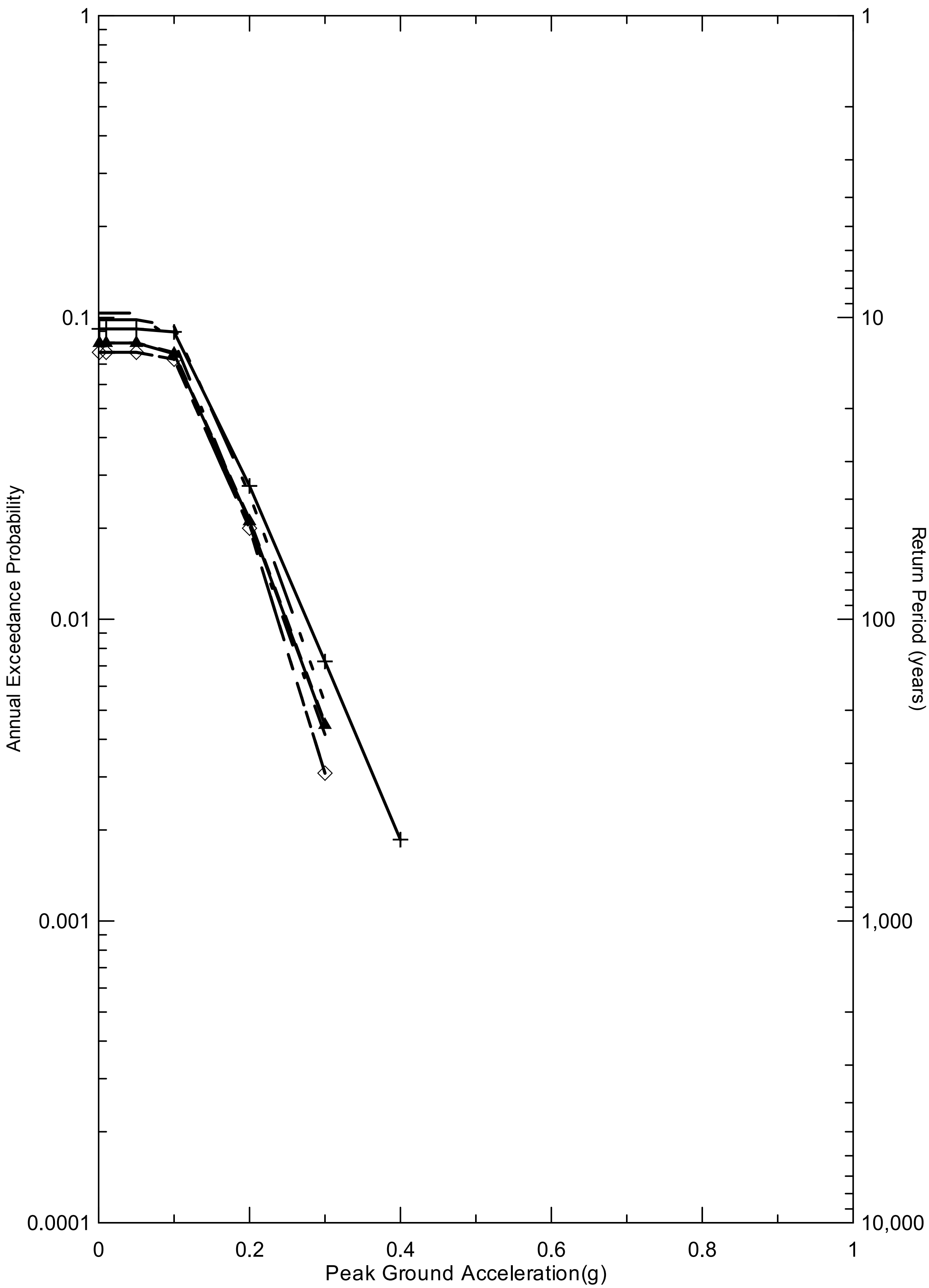


	PEER PSHA VERIFICATION	TEST SET 2, CASE 5, SITE 1 EARLY RESULTS	Figure 3.114

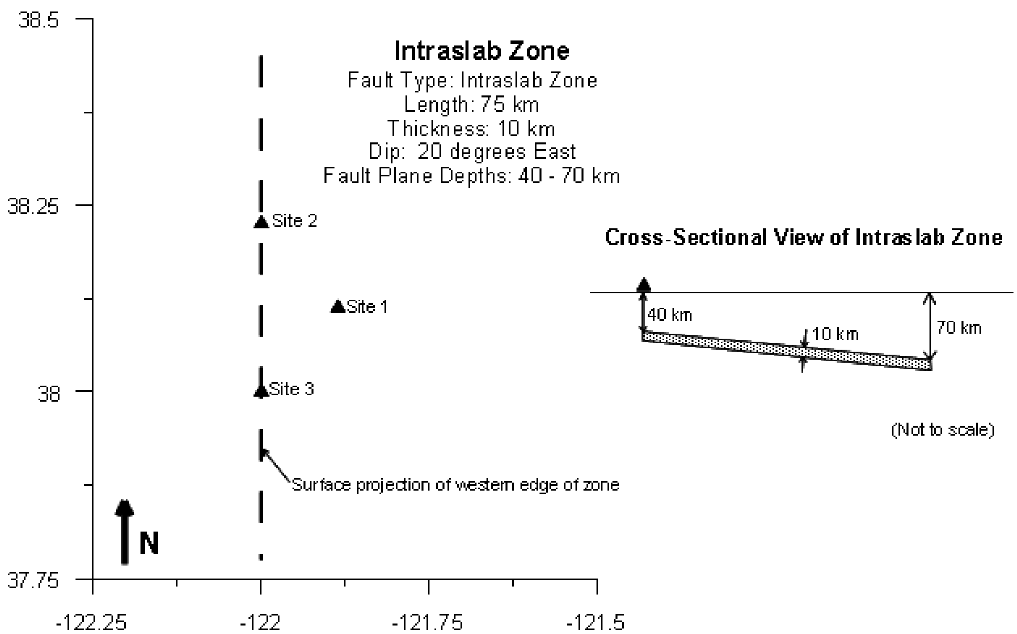


(Coordinates are in Set2_Rev2_Coordinates_Results.xls)

PEER PSHA VERIFICATION	FAULT AND SITE GEOMETRY FOR CASE 6	Figure 3.115

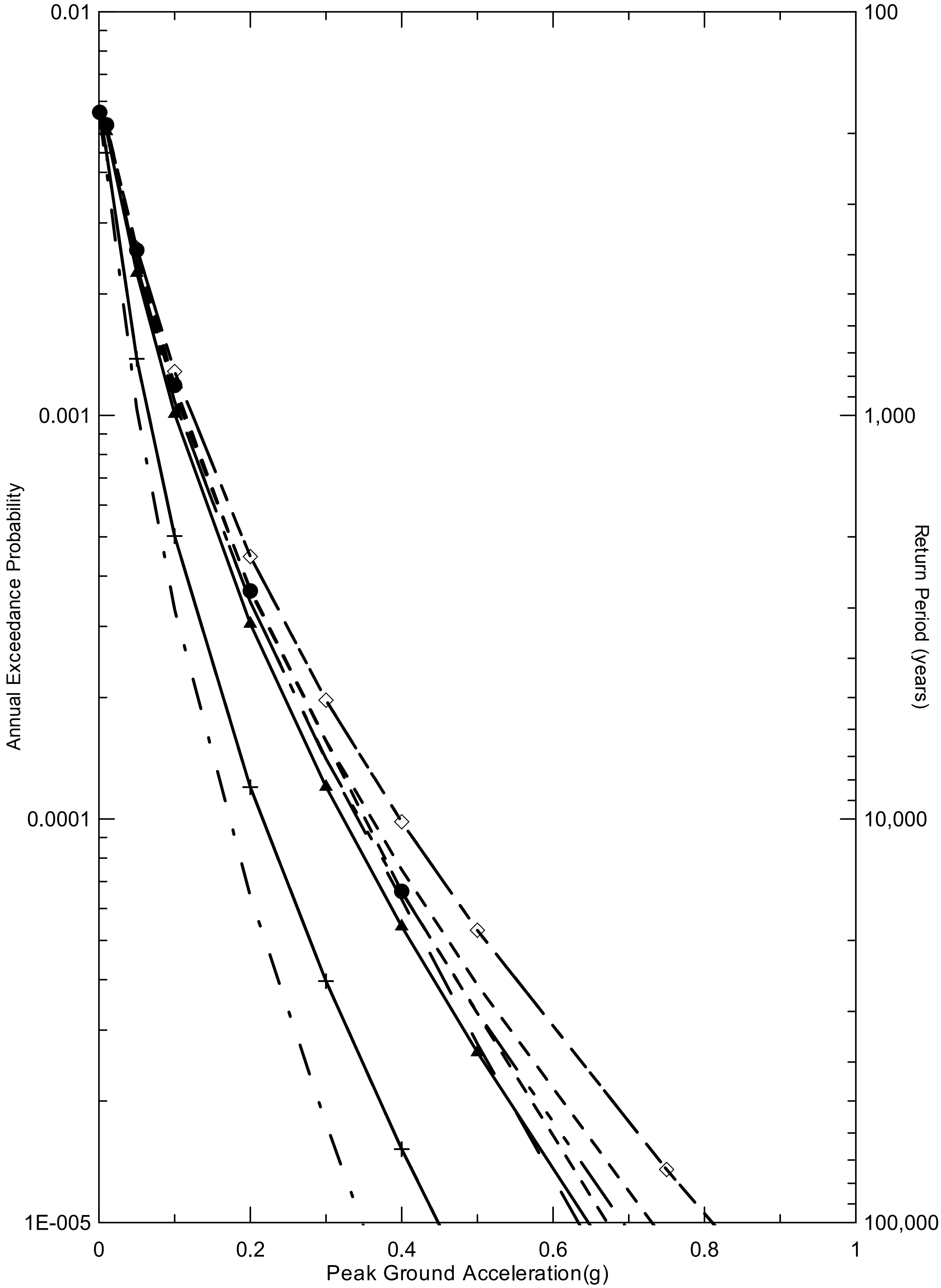


	PEER PSHA VERIFICATION	TEST SET 2, CASE 6, SITE 1 EARLY RESULTS	Figure 3.116



(Coordinates are in Set2_Rev2_Coordinates_Results.xls)

	PEER PSHA VERIFICATION	FAULT AND SITE GEOMETRY FOR CASE 7	Figure 3.117



	PEER PSHA VERIFICATION	TEST SET 2, CASE 7, SITE 1 EARLY RESULTS	Figure 3.118

PEER REPORTS

PEER reports are available individually or by yearly subscription. PEER reports can be ordered at http://peer.berkeley.edu/publications/peer_reports.html or by contacting the Pacific Earthquake Engineering Research Center, 1301 South 46th Street, Richmond, CA 94804-4698. Tel.: (510) 665-3448; Fax: (510) 665-3456; Email: peer_editor@berkeley.edu

PEER 2010/01 *Structural Response and Cost Characterization of Bridge Construction Using Seismic Performance Enhancement Strategies.* Ady Aviram, Božidar Stojadinović, Gustavo J. Parra-Montesinos, and Kevin R. Mackie. March 2010.

PEER 2009/03 *The Integration of Experimental and Simulation Data in the Study of Reinforced Concrete Bridge Systems Including Soil-Foundation-Structure Interaction.* Matthew Dryden and Gregory L. Fenves. November 2009.

PEER 2009/02 *Improving Earthquake Mitigation through Innovations and Applications in Seismic Science, Engineering, Communication, and Response. Proceedings of a U.S.-Iran Seismic Workshop.* October 2009.

PEER 2009/01 *Evaluation of Ground Motion Selection and Modification Methods: Predicting Median Interstory Drift Response of Buildings.* Curt B. Haselton, Ed. June 2009.

PEER 2008/10 *Technical Manual for Strata.* Albert R. Kottke and Ellen M. Rathje. February 2009.

PEER 2008/09 *NGA Model for Average Horizontal Component of Peak Ground Motion and Response Spectra.* Brian S.-J. Chiou and Robert R. Youngs. November 2008.

PEER 2008/08 *Toward Earthquake-Resistant Design of Concentrically Braced Steel Structures.* Patxi Uriz and Stephen A. Mahin. November 2008.

PEER 2008/07 *Using OpenSees for Performance-Based Evaluation of Bridges on Liquefiable Soils.* Stephen L. Kramer, Pedro Arduino, and HyungSuk Shin. November 2008.

PEER 2008/06 *Shaking Table Tests and Numerical Investigation of Self-Centering Reinforced Concrete Bridge Columns.* Hyung IL Jeong, Junichi Sakai, and Stephen A. Mahin. September 2008.

PEER 2008/05 *Performance-Based Earthquake Engineering Design Evaluation Procedure for Bridge Foundations Undergoing Liquefaction-Induced Lateral Ground Displacement.* Christian A. Ledezma and Jonathan D. Bray. August 2008.

PEER 2008/04 *Benchmarking of Nonlinear Geotechnical Ground Response Analysis Procedures.* Jonathan P. Stewart, Annie On-Lei Kwok, Yousseff M. A. Hashash, Neven Matasovic, Robert Pyke, Zhiliang Wang, and Zhaohui Yang. August 2008.

PEER 2008/03 *Guidelines for Nonlinear Analysis of Bridge Structures in California.* Ady Aviram, Kevin R. Mackie, and Božidar Stojadinović. August 2008.

PEER 2008/02 *Treatment of Uncertainties in Seismic-Risk Analysis of Transportation Systems.* Evangelos Stergiou and Anne S. Kiremidjian. July 2008.

PEER 2008/01 *Seismic Performance Objectives for Tall Buildings.* William T. Holmes, Charles Kircher, William Petak, and Nabih Youssef. August 2008.

PEER 2007/12 *An Assessment to Benchmark the Seismic Performance of a Code-Conforming Reinforced Concrete Moment-Frame Building.* Curt Haselton, Christine A. Goulet, Judith Mitrani-Reiser, James L. Beck, Gregory G. Deierlein, Keith A. Porter, Jonathan P. Stewart, and Ertugrul Taciroglu. August 2008.

PEER 2007/11 *Bar Buckling in Reinforced Concrete Bridge Columns.* Wayne A. Brown, Dawn E. Lehman, and John F. Stanton. February 2008.

PEER 2007/10 *Computational Modeling of Progressive Collapse in Reinforced Concrete Frame Structures.* Mohamed M. Talaat and Khalid M. Mosalam. May 2008.

PEER 2007/09 *Integrated Probabilistic Performance-Based Evaluation of Benchmark Reinforced Concrete Bridges.* Kevin R. Mackie, John-Michael Wong, and Božidar Stojadinović. January 2008.

PEER 2007/08 *Assessing Seismic Collapse Safety of Modern Reinforced Concrete Moment-Frame Buildings.* Curt B. Haselton and Gregory G. Deierlein. February 2008.

PEER 2007/07 *Performance Modeling Strategies for Modern Reinforced Concrete Bridge Columns.* Michael P. Berry and Marc O. Eberhard. April 2008.

PEER 2007/06 *Development of Improved Procedures for Seismic Design of Buried and Partially Buried Structures.* Linda Al Atik and Nicholas Sitar. June 2007.

PEER 2007/05 *Uncertainty and Correlation in Seismic Risk Assessment of Transportation Systems.* Renee G. Lee and Anne S. Kiremidjian. July 2007.

PEER 2007/04 *Numerical Models for Analysis and Performance-Based Design of Shallow Foundations Subjected to Seismic Loading.* Sivapalan Gajan, Tara C. Hutchinson, Bruce L. Kutter, Prishati Raychowdhury, José A. Ugalde, and Jonathan P. Stewart. May 2008.

PEER 2007/03 *Beam-Column Element Model Calibrated for Predicting Flexural Response Leading to Global Collapse of RC Frame Buildings.* Curt B. Haselton, Abbie B. Liel, Sarah Taylor Lange, and Gregory G. Deierlein. May 2008.

PEER 2007/02 *Campbell-Bozorgnia NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters.* Kenneth W. Campbell and Yousef Bozorgnia. May 2007.

PEER 2007/01 *Boore-Atkinson NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters.* David M. Boore and Gail M. Atkinson. May. May 2007.

PEER 2006/12 *Societal Implications of Performance-Based Earthquake Engineering.* Peter J. May. May 2007.

PEER 2006/11 *Probabilistic Seismic Demand Analysis Using Advanced Ground Motion Intensity Measures, Attenuation Relationships, and Near-Fault Effects.* Polsak Tothong and C. Allin Cornell. March 2007.

PEER 2006/10 *Application of the PEER PBEE Methodology to the I-880 Viaduct.* Sashi Kunnath. February 2007.

PEER 2006/09 *Quantifying Economic Losses from Travel Forgone Following a Large Metropolitan Earthquake.* James Moore, Sungbin Cho, Yue Yue Fan, and Stuart Werner. November 2006.

PEER 2006/08 *Vector-Valued Ground Motion Intensity Measures for Probabilistic Seismic Demand Analysis*. Jack W. Baker and C. Allin Cornell. October 2006.

PEER 2006/07 *Analytical Modeling of Reinforced Concrete Walls for Predicting Flexural and Coupled–Shear-Flexural Responses*. Kutay Orakcal, Leonardo M. Massone, and John W. Wallace. October 2006.

PEER 2006/06 *Nonlinear Analysis of a Soil-Drilled Pier System under Static and Dynamic Axial Loading.* Gang Wang and Nicholas Sitar. November 2006.

PEER 2006/05 *Advanced Seismic Assessment Guidelines.* Paolo Bazzurro, C. Allin Cornell, Charles Menun, Maziar Motahari, and Nicolas Luco. September 2006.

PEER 2006/04 *Probabilistic Seismic Evaluation of Reinforced Concrete Structural Components and Systems.* Tae Hyung Lee and Khalid M. Mosalam. August 2006.

PEER 2006/03 *Performance of Lifelines Subjected to Lateral Spreading.* Scott A. Ashford and Teerawut Juirnarongrit. July 2006.

PEER 2006/02 *Pacific Earthquake Engineering Research Center Highway Demonstration Project.* Anne Kiremidjian, James Moore, Yue Yue Fan, Nesrin Basoz, Ozgur Yazali, and Meredith Williams. April 2006.

PEER 2006/01 *Bracing Berkeley. A Guide to Seismic Safety on the UC Berkeley Campus.* Mary C. Comerio, Stephen Tobriner, and Ariane Fehrenkamp. January 2006.

PEER 2005/16 *Seismic Response and Reliability of Electrical Substation Equipment and Systems.* Junho Song, Armen Der Kiureghian, and Jerome L. Sackman. April 2006.

PEER 2005/15 *CPT-Based Probabilistic Assessment of Seismic Soil Liquefaction Initiation.* R. E. S. Moss, R. B. Seed, R. E. Kayen, J. P. Stewart, and A. Der Kiureghian. April 2006.

PEER 2005/14 *Workshop on Modeling of Nonlinear Cyclic Load-Deformation Behavior of Shallow Foundations.* Bruce L. Kutter, Geoffrey Martin, Tara Hutchinson, Chad Harden, Sivapalan Gajan, and Justin Phalen. March 2006.

PEER 2005/13 *Stochastic Characterization and Decision Bases under Time-Dependent Aftershock Risk in Performance-Based Earthquake Engineering.* Gee Liek Yeo and C. Allin Cornell. July 2005.

PEER 2005/12 *PEER Testbed Study on a Laboratory Building: Exercising Seismic Performance Assessment.* Mary C. Comerio, editor. November 2005.

PEER 2005/11 *Van Nuys Hotel Building Testbed Report: Exercising Seismic Performance Assessment.* Helmut Krawinkler, editor. October 2005.

PEER 2005/10 *First NEES/E-Defense Workshop on Collapse Simulation of Reinforced Concrete Building Structures.* September 2005.

PEER 2005/09 *Test Applications of Advanced Seismic Assessment Guidelines.* Joe Maffei, Karl Telleen, Danya Mohr, William Holmes, and Yuki Nakayama. August 2006.

PEER 2005/08 *Damage Accumulation in Lightly Confined Reinforced Concrete Bridge Columns.* R. Tyler Ranf, Jared M. Nelson, Zach Price, Marc O. Eberhard, and John F. Stanton. April 2006.

PEER 2005/07 *Experimental and Analytical Studies on the Seismic Response of Freestanding and Anchored Laboratory Equipment.* Dimitrios Konstantinidis and Nicos Makris. January 2005.

PEER 2005/06 *Global Collapse of Frame Structures under Seismic Excitations*. Luis F. Ibarra and Helmut Krawinkler. September 2005.

PEER 2005//05 *Performance Characterization of Bench- and Shelf-Mounted Equipment.* Samit Ray Chaudhuri and Tara C. Hutchinson. May 2006.

PEER 2005/04 *Numerical Modeling of the Nonlinear Cyclic Response of Shallow Foundations.* Chad Harden, Tara Hutchinson, Geoffrey R. Martin, and Bruce L. Kutter. August 2005.

PEER 2005/03 *A Taxonomy of Building Components for Performance-Based Earthquake Engineering.* Keith A. Porter. September 2005.

PEER 2005/02 *Fragility Basis for California Highway Overpass Bridge Seismic Decision Making*. Kevin R. Mackie and Božidar Stojadinović. June 2005.

PEER 2005/01 *Empirical Characterization of Site Conditions on Strong Ground Motion.* Jonathan P. Stewart, Yoojoong Choi, and Robert W. Graves. June 2005.

PEER 2004/09 *Electrical Substation Equipment Interaction: Experimental Rigid Conductor Studies.* Christopher Stearns and André Filiatrault. February 2005.

PEER 2004/08 *Seismic Qualification and Fragility Testing of Line Break 550-kV Disconnect Switches.* Shakhzod M. Takhirov, Gregory L. Fenves, and Eric Fujisaki. January 2005.

PEER 2004/07 *Ground Motions for Earthquake Simulator Qualification of Electrical Substation Equipment.* Shakhzod M. Takhirov, Gregory L. Fenves, Eric Fujisaki, and Don Clyde. January 2005.

PEER 2004/06 *Performance-Based Regulation and Regulatory Regimes.* Peter J. May and Chris Koski. September 2004.

PEER 2004/05 *Performance-Based Seismic Design Concepts and Implementation: Proceedings of an International Workshop.* Peter Fajfar and Helmut Krawinkler, editors. September 2004.

PEER 2004/04 *Seismic Performance of an Instrumented Tilt-up Wall Building.* James C. Anderson and Vitelmo V. Bertero. July 2004.

PEER 2004/03 *Evaluation and Application of Concrete Tilt-up Assessment Methodologies.* Timothy Graf and James O. Malley. October 2004.

PEER 2004/02 *Analytical Investigations of New Methods for Reducing Residual Displacements of Reinforced Concrete Bridge Columns.* Junichi Sakai and Stephen A. Mahin. August 2004.

PEER 2004/01 *Seismic Performance of Masonry Buildings and Design Implications.* Kerri Anne Taeko Tokoro, James C. Anderson, and Vitelmo V. Bertero. February 2004.

PEER 2003/18 *Performance Models for Flexural Damage in Reinforced Concrete Columns.* Michael Berry and Marc Eberhard. August 2003.

PEER 2003/17 *Predicting Earthquake Damage in Older Reinforced Concrete Beam-Column Joints.* Catherine Pagni and Laura Lowes. October 2004.

PEER 2003/16 *Seismic Demands for Performance-Based Design of Bridges.* Kevin Mackie and Božidar Stojadinović. August 2003.

PEER 2003/15 *Seismic Demands for Nondeteriorating Frame Structures and Their Dependence on Ground Motions.* Ricardo Antonio Medina and Helmut Krawinkler. May 2004.

PEER 2003/14 *Finite Element Reliability and Sensitivity Methods for Performance-Based Earthquake Engineering.* Terje Haukaas and Armen Der Kiureghian. April 2004.

PEER 2003/13 *Effects of Connection Hysteretic Degradation on the Seismic Behavior of Steel Moment-Resisting Frames.* Janise E. Rodgers and Stephen A. Mahin. March 2004.

PEER 2003/12 *Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies.* William T. Holmes and Mary C. Comerio. October 2003.

PEER 2003/11 *Fifth U.S.-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures.* February 2004.

PEER 2003/10 *A Beam-Column Joint Model for Simulating the Earthquake Response of Reinforced Concrete Frames.* Laura N. Lowes, Nilanjan Mitra, and Arash Altoontash. February 2004.

PEER 2003/09 *Sequencing Repairs after an Earthquake: An Economic Approach.* Marco Casari and Simon J. Wilkie. April 2004.

PEER 2003/08 *A Technical Framework for Probability-Based Demand and Capacity Factor Design (DCFD) Seismic Formats.* Fatemeh Jalayer and C. Allin Cornell. November 2003.

PEER 2003/07 *Uncertainty Specification and Propagation for Loss Estimation Using FOSM Methods.* Jack W. Baker and C. Allin Cornell. September 2003.

PEER 2003/06 *Performance of Circular Reinforced Concrete Bridge Columns under Bidirectional Earthquake Loading*. Mahmoud M. Hachem, Stephen A. Mahin, and Jack P. Moehle. February 2003.

PEER 2003/05 *Response Assessment for Building-Specific Loss Estimation.* Eduardo Miranda and Shahram Taghavi. September 2003.

PEER 2003/04 *Experimental Assessment of Columns with Short Lap Splices Subjected to Cyclic Loads*. Murat Melek, John W. Wallace, and Joel Conte. April 2003.

PEER 2003/03 *Probabilistic Response Assessment for Building-Specific Loss Estimation.* Eduardo Miranda and Hesameddin Aslani. September 2003.

PEER 2003/02 *Software Framework for Collaborative Development of Nonlinear Dynamic Analysis Program.* Jun Peng and Kincho H. Law. September 2003.

PEER 2003/01 *Shake Table Tests and Analytical Studies on the Gravity Load Collapse of Reinforced Concrete Frames.* Kenneth John Elwood and Jack P. Moehle. November 2003.

PEER 2002/24 *Performance of Beam to Column Bridge Joints Subjected to a Large Velocity Pulse.* Natalie Gibson, André Filiatrault, and Scott A. Ashford. April 2002.

PEER 2002/23 *Effects of Large Velocity Pulses on Reinforced Concrete Bridge Columns.* Greg L. Orozco and Scott A. Ashford. April 2002.

PEER 2002/22 *Characterization of Large Velocity Pulses for Laboratory Testing.* Kenneth E. Cox and Scott A. Ashford. April 2002.

PEER 2002/21 *Fourth U.S.-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures*. December 2002.

PEER 2002/20 *Barriers to Adoption and Implementation of PBEE Innovations.* Peter J. May. August 2002.

PEER 2002/19 *Economic-Engineered Integrated Models for Earthquakes: Socioeconomic Impacts.* Peter Gordon, James E. Moore II, and Harry W. Richardson. July 2002.

PEER 2002/18 *Assessment of Reinforced Concrete Building Exterior Joints with Substandard Details.* Chris P. Pantelides, Jon Hansen, Justin Nadauld, and Lawrence D. Reaveley. May 2002.

PEER 2002/17 *Structural Characterization and Seismic Response Analysis of a Highway Overcrossing Equipped with Elastomeric Bearings and Fluid Dampers: A Case Study.* Nicos Makris and Jian Zhang. November 2002.

PEER 2002/16 *Estimation of Uncertainty in Geotechnical Properties for Performance-Based Earthquake Engineering.* Allen L. Jones, Steven L. Kramer, and Pedro Arduino. December 2002.

PEER 2002/15 *Seismic Behavior of Bridge Columns Subjected to Various Loading Patterns.* Asadollah Esmaeily-Gh. and Yan Xiao. December 2002.

PEER 2002/14 *Inelastic Seismic Response of Extended Pile Shaft Supported Bridge Structures.* T.C. Hutchinson, R.W. Boulanger, Y.H. Chai, and I.M. Idriss. December 2002.

PEER 2002/13 *Probabilistic Models and Fragility Estimates for Bridge Components and Systems.* Paolo Gardoni, Armen Der Kiureghian, and Khalid M. Mosalam. June 2002.

PEER 2002/12 *Effects of Fault Dip and Slip Rake on Near-Source Ground Motions: Why Chi-Chi Was a Relatively Mild M7.6 Earthquake.* Brad T. Aagaard, John F. Hall, and Thomas H. Heaton. December 2002.

PEER 2002/11 *Analytical and Experimental Study of Fiber-Reinforced Strip Isolators*. James M. Kelly and Shakhzod M. Takhirov. September 2002.

PEER 2002/10 *Centrifuge Modeling of Settlement and Lateral Spreading with Comparisons to Numerical Analyses***.** Sivapalan Gajan and Bruce L. Kutter. January 2003.

PEER 2002/09 *Documentation and Analysis of Field Case Histories of Seismic Compression during the 1994 Northridge, California, Earthquake.* Jonathan P. Stewart, Patrick M. Smith, Daniel H. Whang, and Jonathan D. Bray. October 2002.

PEER 2002/08 *Component Testing, Stability Analysis and Characterization of Buckling-Restrained Unbonded Braces™.* Cameron Black, Nicos Makris, and Ian Aiken. September 2002.

PEER 2002/07 *Seismic Performance of Pile-Wharf Connections.* Charles W. Roeder, Robert Graff, Jennifer Soderstrom, and Jun Han Yoo. December 2001.

PEER 2002/06 *The Use of Benefit-Cost Analysis for Evaluation of Performance-Based Earthquake Engineering Decisions*. Richard O. Zerbe and Anthony Falit-Baiamonte. September 2001.

PEER 2002/05 *Guidelines, Specifications, and Seismic Performance Characterization of Nonstructural Building Components and Equipment*. André Filiatrault, Constantin Christopoulos, and Christopher Stearns. September 2001.

PEER 2002/04 *Consortium of Organizations for Strong-Motion Observation Systems and the Pacific Earthquake Engineering Research Center Lifelines Program: Invited Workshop on Archiving and Web Dissemination of Geotechnical Data, 4–5 October 2001*. September 2002.

PEER 2002/03 *Investigation of Sensitivity of Building Loss Estimates to Major Uncertain Variables for the Van Nuys Testbed.* Keith A. Porter, James L. Beck, and Rustem V. Shaikhutdinov. August 2002.

PEER 2002/02 *The Third U.S.-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures*. July 2002.

PEER 2002/01 *Nonstructural Loss Estimation: The UC Berkeley Case Study.* Mary C. Comerio and John C. Stallmeyer. December 2001.

PEER 2001/16 *Statistics of SDF-System Estimate of Roof Displacement for Pushover Analysis of Buildings.* Anil K. Chopra, Rakesh K. Goel, and Chatpan Chintanapakdee. December 2001.

PEER 2001/15 *Damage to Bridges during the 2001 Nisqually Earthquake.* R. Tyler Ranf, Marc O. Eberhard, and Michael P. Berry. November 2001.

PEER 2001/14 *Rocking Response of Equipment Anchored to a Base Foundation.* Nicos Makris and Cameron J. Black. September 2001.

PEER 2001/13 *Modeling Soil Liquefaction Hazards for Performance-Based Earthquake Engineering.* Steven L. Kramer and Ahmed-W. Elgamal. February 2001.

PEER 2001/12 *Development of Geotechnical Capabilities in OpenSees.* Boris Jeremi . September 2001.

PEER 2001/11 *Analytical and Experimental Study of Fiber-Reinforced Elastomeric Isolators*. James M. Kelly and Shakhzod M. Takhirov. September 2001.

PEER 2001/10 *Amplification Factors for Spectral Acceleration in Active Regions.* Jonathan P. Stewart, Andrew H. Liu, Yoojoong Choi, and Mehmet B. Baturay. December 2001.

PEER 2001/09 *Ground Motion Evaluation Procedures for Performance-Based Design.* Jonathan P. Stewart, Shyh-Jeng Chiou, Jonathan D. Bray, Robert W. Graves, Paul G. Somerville, and Norman A. Abrahamson. September 2001.

PEER 2001/08 *Experimental and Computational Evaluation of Reinforced Concrete Bridge Beam-Column Connections for Seismic Performance*. Clay J. Naito, Jack P. Moehle, and Khalid M. Mosalam. November 2001.

PEER 2001/07 *The Rocking Spectrum and the Shortcomings of Design Guidelines.* Nicos Makris and Dimitrios Konstantinidis. August 2001.

PEER 2001/06 *Development of an Electrical Substation Equipment Performance Database for Evaluation of Equipment Fragilities*. Thalia Agnanos. April 1999.

PEER 2001/05 *Stiffness Analysis of Fiber-Reinforced Elastomeric Isolators.* Hsiang-Chuan Tsai and James M. Kelly. May 2001.

PEER 2001/04 *Organizational and Societal Considerations for Performance-Based Earthquake Engineering.* Peter J. May. April 2001.

PEER 2001/03 *A Modal Pushover Analysis Procedure to Estimate Seismic Demands for Buildings: Theory and Preliminary Evaluation.* Anil K. Chopra and Rakesh K. Goel. January 2001.

PEER 2001/02 *Seismic Response Analysis of Highway Overcrossings Including Soil-Structure Interaction.* Jian Zhang and Nicos Makris. March 2001.

PEER 2001/01 *Experimental Study of Large Seismic Steel Beam-to-Column Connections.* Egor P. Popov and Shakhzod M. Takhirov. November 2000.

PEER 2000/10 *The Second U.S.-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures.* March 2000.

PEER 2000/09 *Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey.* Halil Sezen, Kenneth J. Elwood, Andrew S. Whittaker, Khalid Mosalam, John J. Wallace, and John F. Stanton. December 2000.

PEER 2000/08 *Behavior of Reinforced Concrete Bridge Columns Having Varying Aspect Ratios and Varying Lengths of Confinement.* Anthony J. Calderone, Dawn E. Lehman, and Jack P. Moehle. January 2001.

PEER 2000/07 *Cover-Plate and Flange-Plate Reinforced Steel Moment-Resisting Connections.* Taejin Kim, Andrew S. Whittaker, Amir S. Gilani, Vitelmo V. Bertero, and Shakhzod M. Takhirov. September 2000.

PEER 2000/06 *Seismic Evaluation and Analysis of 230-kV Disconnect Switches.* Amir S. J. Gilani, Andrew S. Whittaker, Gregory L. Fenves, Chun-Hao Chen, Henry Ho, and Eric Fujisaki. July 2000.

PEER 2000/05 *Performance-Based Evaluation of Exterior Reinforced Concrete Building Joints for Seismic Excitation.* Chandra Clyde, Chris P. Pantelides, and Lawrence D. Reaveley. July 2000.

PEER 2000/04 *An Evaluation of Seismic Energy Demand: An Attenuation Approach.* Chung-Che Chou and Chia-Ming Uang. July 1999.

PEER 2000/03 *Framing Earthquake Retrofitting Decisions: The Case of Hillside Homes in Los Angeles.* Detlof von Winterfeldt, Nels Roselund, and Alicia Kitsuse. March 2000.

PEER 2000/02 *U.S.-Japan Workshop on the Effects of Near-Field Earthquake Shaking.* Andrew Whittaker, ed. July 2000.

PEER 2000/01 *Further Studies on Seismic Interaction in Interconnected Electrical Substation Equipment.* Armen Der Kiureghian, Kee-Jeung Hong, and Jerome L. Sackman. November 1999.

PEER 1999/14 *Seismic Evaluation and Retrofit of 230-kV Porcelain Transformer Bushings*. Amir S. Gilani, Andrew S. Whittaker, Gregory L. Fenves, and Eric Fujisaki. December 1999.

PEER 1999/13 *Building Vulnerability Studies: Modeling and Evaluation of Tilt-up and Steel Reinforced Concrete Buildings.* John W. Wallace, Jonathan P. Stewart, and Andrew S. Whittaker, editors. December 1999.

PEER 1999/12 *Rehabilitation of Nonductile RC Frame Building Using Encasement Plates and Energy-Dissipating Devices.* Mehrdad Sasani, Vitelmo V. Bertero, James C. Anderson. December 1999.

PEER 1999/11 *Performance Evaluation Database for Concrete Bridge Components and Systems under Simulated Seismic Loads.* Yael D. Hose and Frieder Seible. November 1999.

PEER 1999/10 *U.S.-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures.* December 1999.

PEER 1999/09 *Performance Improvement of Long Period Building Structures Subjected to Severe Pulse-Type Ground Motions*. James C. Anderson, Vitelmo V. Bertero, and Raul Bertero. October 1999.

PEER 1999/08 *Envelopes for Seismic Response Vectors.* Charles Menun and Armen Der Kiureghian. July 1999.

PEER 1999/07 *Documentation of Strengths and Weaknesses of Current Computer Analysis Methods for Seismic Performance of Reinforced Concrete Members.* William F. Cofer. November 1999.

PEER 1999/06 *Rocking Response and Overturning of Anchored Equipment under Seismic Excitations.* Nicos Makris and Jian Zhang. November 1999.

PEER 1999/05 *Seismic Evaluation of 550 kV Porcelain Transformer Bushings.* Amir S. Gilani, Andrew S. Whittaker, Gregory L. Fenves, and Eric Fujisaki. October 1999.

PEER 1999/04 *Adoption and Enforcement of Earthquake Risk-Reduction Measures.* Peter J. May, Raymond J. Burby, T. Jens Feeley, and Robert Wood.

PEER 1999/03 *Task 3 Characterization of Site Response General Site Categories*. Adrian Rodriguez-Marek, Jonathan D. Bray, and Norman Abrahamson. February 1999.

PEER 1999/02 *Capacity-Demand-Diagram Methods for Estimating Seismic Deformation of Inelastic Structures: SDF Systems*. Anil K. Chopra and Rakesh Goel. April 1999.

PEER 1999/01 *Interaction in Interconnected Electrical Substation Equipment Subjected to Earthquake Ground Motions.* Armen Der Kiureghian, Jerome L. Sackman, and Kee-Jeung Hong. February 1999.

PEER 1998/08 *Behavior and Failure Analysis of a Multiple-Frame Highway Bridge in the 1994 Northridge Earthquake.* Gregory L. Fenves and Michael Ellery. December 1998.

PEER 1998/07 *Empirical Evaluation of Inertial Soil-Structure Interaction Effects.* Jonathan P. Stewart, Raymond B. Seed, and Gregory L. Fenves. November 1998.

PEER 1998/06 *Effect of Damping Mechanisms on the Response of Seismic Isolated Structures.* Nicos Makris and Shih-Po Chang. November 1998.

PEER 1998/05 *Rocking Response and Overturning of Equipment under Horizontal Pulse-Type Motions.* Nicos Makris and Yiannis Roussos. October 1998.

PEER 1998/04 *Pacific Earthquake Engineering Research Invitational Workshop Proceedings, May 14–15, 1998: Defining the Links between Planning, Policy Analysis, Economics and Earthquake Engineering.* Mary Comerio and Peter Gordon. September 1998.

PEER 1998/03 *Repair/Upgrade Procedures for Welded Beam to Column Connections.* James C. Anderson and Xiaojing Duan. May 1998.

PEER 1998/02 *Seismic Evaluation of 196 kV Porcelain Transformer Bushings.* Amir S. Gilani, Juan W. Chavez, Gregory L. Fenves, and Andrew S. Whittaker. May 1998.

PEER 1998/01 *Seismic Performance of Well-Confined Concrete Bridge Columns.* Dawn E. Lehman and Jack P. Moehle. December 2000.

ONLINE REPORTS

The following PEER reports are available by Internet only at http://peer.berkeley.edu/publications/peer_reports.html

PEER 2010/106 *Verification of Probabilistic Seismic Hazard Analysis Computer Programs.* Patricia Thomas, Ivan Wong, and Norman Abrahamson. May 2010.

PEER 2010/105 *Structural Engineering Reconnaissance of the April 6, 2009, Abruzzo, Italy, Earthquake, and Lessons Learned.* M. Selim Günay and Khalid M. Mosalam. April 2010.

PEER 2010/103 *Post-Earthquake Traffic Capacity of Modern Bridges in California.* Vesna Terzic and Božidar Stojadinović. March 2010.

PEER 2010/102 *Analysis of Cumulative Absolute Velocity (CAV) and JMA Instrumental Seismic Intensity (I_{JMA}) Using the PEER–NGA Strong Motion Database.* Kenneth W. Campbell and Yousef Bozorgnia. February 2010.

PEER 2009/109 *Simulation and Performance-Based Earthquake Engineering Assessment of Self-Centering Post-Tensioned Concrete Bridge Systems.* Won K. Lee and Sarah L. Billington. December 2009.

PEER 2009/108 *PEER Lifelines Geotechnical Virtual Data Center.* J. Carl Stepp, Daniel J. Ponti, Loren L. Turner, Jennifer N. Swift, Sean Devlin, Yang Zhu, Jean Benoit, and John Bobbitt. September 2009.

PEER 2009/107 *Experimental and Computational Evaluation of Current and Innovative In-Span Hinge Details in Reinforced Concrete Box-Girder Bridges: Part 2: Post-Test Analysis and Design Recommendations.* Matias A. Hube and Khalid M. Mosalam. December 2009.

PEER 2009/106 *Shear Strength Models of Exterior Beam-Column Joints without Transverse Reinforcement.* Sangjoon Park and Khalid M. Mosalam. November 2009.

PEER 2009/105 *Reduced Uncertainty of Ground Motion Prediction Equations through Bayesian Variance Analysis.* Robb Eric S. Moss. November 2009.

PEER 2009/104 *Advanced Implementation of Hybrid Simulation.* Andreas H. Schellenberg, Stephen A. Mahin, Gregory L. Fenves. November 2009.

PEER 2009/103 *Performance Evaluation of Innovative Steel Braced Frames.* T. Y. Yang, Jack P. Moehle, and Božidar Stojadinovic. August 2009.

PEER 2009/102 *Reinvestigation of Liquefaction and Nonliquefaction Case Histories from the 1976 Tangshan Earthquake.* Robb Eric Moss, Robert E. Kayen, Liyuan Tong, Songyu Liu, Guojun Cai, and Jiaer Wu. August 2009.

PEER 2009/101 *Report of the First Joint Planning Meeting for the Second Phase of NEES/E-Defense Collaborative Research on Earthquake Engineering.* Stephen A. Mahin et al. July 2009.

PEER 2008/104 *Experimental and Analytical Study of the Seismic Performance of Retaining Structures.* Linda Al Atik and Nicholas Sitar. January 2009.

PEER 2008/103 *Experimental and Computational Evaluation of Current and Innovative In-Span Hinge Details in Reinforced Concrete Box-Girder Bridges. Part 1: Experimental Findings and Pre-Test Analysis.* Matias A. Hube and Khalid M. Mosalam. January 2009.

PEER 2008/102 *Modeling of Unreinforced Masonry Infill Walls Considering In-Plane and Out-of-Plane Interaction.* Stephen Kadysiewski and Khalid M. Mosalam. January 2009.

PEER 2008/101 *Seismic Performance Objectives for Tall Buildings.* William T. Holmes, Charles Kircher, William Petak, and Nabih Youssef. August 2008.

PEER 2007/101 *Generalized Hybrid Simulation Framework for Structural Systems Subjected to Seismic Loading.* Tarek Elkhoraibi and Khalid M. Mosalam. July 2007.

PEER 2007/100 *Seismic Evaluation of Reinforced Concrete Buildings Including Effects of Masonry Infill Walls.* Alidad Hashemi and Khalid M. Mosalam. July 2007.