RMC Seismic Hazard Curves Toolbox

RMC Seismic Hazard Suite

RMC-CPD-2023-02

January 2024

US Army Corps of Engineers®
Dam and Levee Safety Programs

US Army Corps of Engineers®
Dam and Levee Safety Programs

Cover Photo: U.S. Geological Service (USGS). (2018). *2018 Long-term national seismic hazard map* (public domain). https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map.

US Army Corps of Engineers®
Dam and Levee Safety Programs

RMC Seismic Hazard Curves Toolbox

RMC Seismic Hazard Suite

RMC-CPD-2023-02

January 2024

Prepared by the Risk Management Center

REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	END DATE
Jan 2024	Computer Program Document	N/A	N/A

4. TITLE AND SUBTITLE
RMC Seismic Hazard Curves Toolbox
RMC Seismic Hazard Suite

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
N/A	N/A	N/A
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**
N/A	N/A	N/A

6. AUTHOR(S)
Josh Corbett, Risk Management Center

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Risk Management Center
12596 West Bayaud Ave. Suite 400
Lakewood, CO 80228

8. PERFORMING ORGANIZATION REPORT NUMBER
RMC-CPD-2023-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Risk Management Center
12596 West Bayaud Ave. Suite 400
Lakewood, CO 80228

10. SPONSOR/MONITOR'S ACRONYM(S)
CEIWR-RMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
RMC-CPD-2023-02

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
The spreadsheet tools contained in this toolbox facilitate the downloading, importing, and processing of United States Geological Survey (USGS)-gridded seismic hazard curve data that describes the annual frequency of exceeding a set of ground motions for a range of spectral accelerations and peak ground acceleration that can be adjusted for National Earthquake Hazards Reduction Program (NEHRP) site class effects if necessary.

15. SUBJECT TERMS
Seismic hazard curves, probabilistic seismic hazard analysis, site class adjustment

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
a. REPORT	b. ABSTRACT	c. THIS PAGE		
U	U	U	UU	34

19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER (Include area code)
Tim O'Leary	(502) 315-6599

STANDARD FORM 298 (REF 5/2020)
Prescribed by ANSI Std Z39.18

PREVIOUS EDITION IS OBSOLETE

PREPARED

The results, findings, and recommendations provided in this document are technically sound and consistent with current Corps of Engineers practice.

Josh Corbett, Risk Management Center

REVIEWED

This report has been checked and reviewed and is believed to be in accordance with the standards of the profession.

Tim O'Leary, Risk Management Center

APPROVED

Nate Snorteland, Risk Management Center

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIXES

1. Introduction

The Risk Management Center (RMC) of the U.S. Army Corps of Engineers (USACE) has developed a suite of Microsoft Excel spreadsheets to support risk assessments for dam and levee safety. Each analysis suite is composed of multiple toolboxes (Microsoft Excel workbooks), and each toolbox contains multiple spreadsheet tools or calculation worksheets (Microsoft Excel worksheets). The RMC Seismic Hazard Curves Toolbox is part of the RMC Seismic Hazard Suite.

The information from these spreadsheet tools, along with other pertinent information, informs judgment when developing a list of more and less likely factors and estimating probabilities. USACE best practice for estimating probabilities is to use the best available and multiple methods, but all final probabilities are estimated using team elicitation based on the totality and strength of the evidence.

The RMC continuously works to improve the performance of RMC software; report possible bugs directly to the RMC at the address listed below. Ideally, report suspected errors in written form with a description of the problem and the steps that lead to its occurrence. Suggestions for improvement are also welcomed.

U.S. Army Corps of Engineers
Institute for Water Resources
Risk Management Center
RMC.software@usace.army.mil

2. Terms and Conditions for Use

By using Institute for Water Resources (IWR) software, users voluntarily accept the following terms and conditions. Users that do not agree to these terms and conditions should uninstall the IWR software and return any program materials to IWR and its technical centers. If users downloaded the software and do not have disk media, delete all copies and cease using the software.

2.1. Terms and Conditions for Use of Institute for Water Resources Software

The United States Government, U.S. Army Corps of Engineers, Institute for Water Resources ("IWR"), and IWR's technical centers including the Risk Management Center ("RMC") and Hydrologic Engineering Center ("HEC") grant to the user the rights to install "IWR Software" (either from a disk copy obtained from IWR and IWR's technical centers, a distributor or another user or by downloading it from a network) and to use, copy and/or distribute copies of the IWR Software to other users, subject to the following Terms and Conditions of Use:

- All copies of the IWR Software received or reproduced by or for user pursuant to the authority of this Terms and Conditions of Use will be and remain the property of IWR.

- User may reproduce and distribute the IWR Software provided that the recipient agrees to the Terms and Conditions for Use noted herein.

- IWR and IWR's technical centers are solely responsible for the content of the IWR Software. The IWR Software may not be modified, abridged, decompiled, disassembled, unobfuscated or reverse engineered. The user is solely responsible for the content, interactions, and effects of any and all amendments, if present, whether they be extension modules, language resource bundles, scripts, or any other amendment.

- The name of the IWR Software must not be used to endorse or promote products derived from the IWR Software. Products derived from the IWR Software may not be called the IWR Software nor may any part of the IWR Software name appear within the name of derived products.

- No part of this Terms and Conditions for Use may be modified, deleted or obliterated from the IWR Software.

- No part of the IWR Software may be exported or re-exported in contravention of U.S. export laws or regulations.

2.2. Waiver of Warranty

THE UNITED STATES GOVERNMENT AND ITS AGENCIES, OFFICIALS, REPRESENTATIVES, AND EMPLOYEES, INCLUDING ITS CONTRACTORS AND SUPPLIERS PROVIDE THE IWR SOFTWARE "AS IS," WITHOUT ANY WARRANTY OR CONDITION, EXPRESS, IMPLIED OR STATUTORY, AND SPECIFICALLY DISCLAIM ANY IMPLIED WARRANTIES OF TITLE, MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NON-INFRINGEMENT. Depending on state law, the foregoing disclaimer may not apply to you, and you may also have other legal rights that vary from state to state.

2.3. Limitation of Liability

IN NO EVENT SHALL THE UNITED STATES GOVERNMENT AND ITS AGENCIES, OFFICIALS, REPRESENTATIVES, AND EMPLOYEES, INCLUDING ITS CONTRACTORS AND SUPPLIERS, BE LIABLE FOR LOST PROFITS OR ANY SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF OR IN CONNECTION WITH USE OF THE IWR SOFTWARE REGARDLESS OF CAUSE, INCLUDING NEGLIGENCE. THE UNITED STATES GOVERNMENT'S LIABILITY, AND THE LIABILITY OF ITS AGENCIES, OFFICIALS, REPRESENTATIVES, AND EMPLOYEES, INCLUDING ITS CONTRACTORS AND SUPPLIERS, TO YOU OR ANY THIRD PARTIES IN ANY CIRCUMSTANCE IS LIMITED TO THE REPLACEMENT OF CERTIFIED COPIES OF THE IWR SOFTWARE WITH IDENTIFIED ERRORS CORRECTED. Depending on state law, the above limitation or exclusion may not apply to you.

2.4. Indemnity

As a voluntary user of the IWR Software you agree to indemnify and hold the United States Government, and its agencies, officials, representatives, and employees, including its contractors and suppliers, harmless from any claim or demand, including reasonable attorneys' fees, made by any third party due to or arising out of your use of the IWR Software or breach of this Agreement or your violation of any law or the rights of a third party.

3. General Overview

3.1. Getting Started

Copy or download the toolbox file to the computer. To open the toolbox file, either:

- Find the file on the computer and double-click it. This opens the file in Microsoft Excel.
- Open Microsoft Excel and use the application to open the file: Once Microsoft Excel is open, go to the File menu at the top of the window and select Open.

The toolbox is an Excel binary workbook (.xlsb) that uses macros. You may need to enable the macros, either before opening the file or by clicking "Enable Content" in the yellow Security Warning message bar with a shield icon that appears after the file is opened. The actual message in the message bar will vary depending on the computer's settings and installed add-ins. Figure 1 displays examples of different wordings that may appear in the message bar.

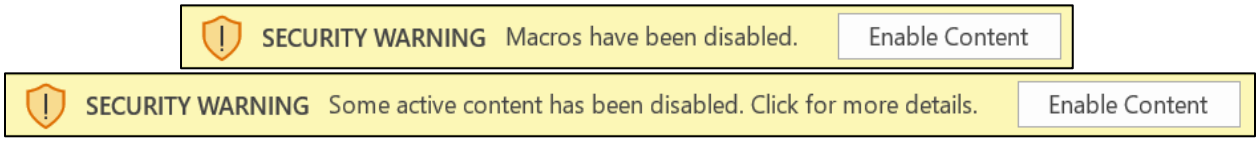

Figure 1. Security warning message bars with the "Enable Content" option to enable macros.

3.2. Organization

Although the toolbox does not provide a calculation cover sheet, adding one is strongly recommended. A calculation cover sheet captures project information, a description and purpose of the calculation, the assumptions for critical input parameters, a summary of the major conclusion and results, and a revision history.

Each toolbox has a similar appearance and organizational structure:

- The first worksheet, About, summarizes the purpose of the toolbox and gives contact information for the RMC software development team.
- The second worksheet, Terms and Conditions, contains the terms and conditions for use of the toolbox (IWR software).
- The third worksheet, Version History, contains the revision history. Semantic versioning is used in the format of MAJOR.MINOR.PATCH:
  - MAJOR – significant worksheet changes not compatible with previous versions.
  - MINOR – additional features or enhancements that do not fundamentally change the calculations.
  - PATCH – backward-compatible bug fixes.

- The fourth worksheet, References, lists the references cited for each calculation worksheet.

The workbook and worksheets are not protected to prevent unwanted changes. However, because the toolbox has user-defined functions (UDFs) and subroutines in Visual Basic, you cannot directly copy worksheets to another workbook without potentially losing functionality. A note in a bold red font at the upper right margin indicates if the selected worksheet includes such features.

At the top of each calculation worksheet, input information for the preparer and checker for quality control (QC) documentation and the calculation title in case multiple copies of the worksheet are created for different analysis scenarios (Figure 2). The footer of each calculation worksheet contains the version number, which can be cross-referenced with the revision history on the third worksheet.

Prepared by:		Office:		Date:	
Checked by:		Office:		Date:	
Calculation Title:					

Figure 2. Calculation worksheet heading.

User-specified input includes values and selections from drop-down lists. User input cells are light yellow, and these cells are unprotected. When cells use drop-down lists, a note in blue font in the right margin of the row alerts the user to use the drop-down list. Conditional formatting applies a gray background to cells that are not based on a user selection. When a user-specified value or calculated value is outside of acceptable ranges, the cell is orange to indicate caution to the user.

All units for user-specified input values are clearly labeled. Most user-specified input values use English units. However, values may be in metric where metric units are more common in practice (e.g., particle size in millimeters or permeability in centimeters per second). The toolbox may convert English units to metric units to perform some calculations or if required for a specific formula based on the reference material for the equation.

If the calculation worksheet is a function of headwater level, up to seven headwater and tailwater levels may be specified at the top of the worksheet. Tailwater may be required to calculate the net hydraulic head and hydraulic gradient. Specify the elevation datum by selecting one of three options from the drop-down list: ft-NAVD88, ft-NGVD29, and Other. The two datum selections include English units of length (feet). If Other is selected, provide a user-specified datum along with feet (e.g., ft-MSL [Mean Sea Level]). Figure 3 through Figure 5 illustrate the three possible scenarios.

Elevation datum		ft-NAVD88		Specify datum				◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-NAVD88)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-NAVD88)

Figure 3. Headwater and tailwater input: NAVD88.

Elevation datum		ft-NGVD29		Specify datum				◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-NGVD29)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-NGVD29)

Figure 4. Headwater and tailwater input: NGVD29.

Elevation datum	Other		Specify datum	ft-MSL			◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-MSL)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-MSL)

Figure 5. Headwater and tailwater input: User-specified datum.

Most calculation worksheets break down complex analysis into computational steps following a logical sequence (Figure 6). Some simpler worksheets do not have steps. Generally, different methodologies are unique worksheets. Some worksheets may include multiple methodologies, which are labeled as options (Figure 7).

Step 1: Select the method of analysis

Figure 6. Example of step banner.

Option 1: Riverside blanket (top stratum) for Cases 5, 7, and 8

Figure 7. Example of option banner.

Some calculation worksheets can perform either a deterministic or probabilistic analysis. Although not required to perform a probabilistic analysis, Palisade @RISK software (standalone version or as part of the Palisade DecisionTools Suite) can customize the probabilistic analysis. A note appears in a bold red font at the upper right-hand margin of a calculation worksheet indicating if this feature is included with the toolbox.

User notes generally appear in the right margin of each calculation worksheet. Some notes are in blue or red font for heightened awareness. These notes include references to source materials for equations, figures, tables, pages, etc. If the RMC modified the source material, the reference citation says “adapted from” instead of “from.”

Tabular and/or graphical summaries are generally the primary output of the toolbox. The UDFs in the PlotScale module change the minimum and maximum values of the x-axis and y-axis for charts. If the calculation worksheet is a function of headwater level, you can define up to five headwater levels of interest and plot them as vertical reference lines. By selecting the chart and then selecting the Filter icon to display the filter pane, you can choose which data series to display. This is useful when computing the results from multiple methodologies, but not all are applicable or desired to display.

4. Background

The United States Geological Survey (USGS) develops and maintains seismic hazard maps for the United States (U.S.) and its territories using a probabilistic seismic hazard analysis (PSHA) framework. The USGS also developed seismic hazard maps as part of a United States Agency for International Development (USAID) effort (e.g., Haiti and Afghanistan).

When USGS develops and publishes seismic hazard maps, the underlying map data is publicly released in the USGS Data Releases section at https://www.sciencebase.gov/catalog/. The map data is released as gridded data (on latitude and longitude) for various ground motion intensity measures and site classes.

Modern datasets have gridded data available for eight National Earthquake Hazards Reduction Program (NEHRP) site classes (Federal Emergency Management Agency [FEMA] 2020) and twenty-two ground motion intensity measures, excluding peak ground velocity (PGV) (Petersen et al. 2020). Legacy data sets generally have gridded data available only for NEHRP site class boundary B/C (very dense soil and soft rock) and three ground motion intensity measures: peak ground acceleration (PGA), 0.2-second spectral acceleration, and 1-second SA. Depending on the legacy dataset, additional site classes or SAs may be available. The grid spacing varies by model to provide adequate resolution.

The USGS-developed web-based tools to extract site data, such as the USGS Earthquake Hazard Toolbox (https://earthquake.usgs.gov/nshmp/). While the web-based tools are very helpful in the quick visualization of the seismic hazard at a site, they are often cumbersome when extracting the data for further processing. This toolbox provides a convenient means for importing USGS data into Microsoft Excel for further processing and plotting.

5. Modern NSHM

The Modern NSHM worksheet facilitates the importing and processing of USGS modern datasets from the USGS Earthquake Hazard Toolbox (https://earthquake.usgs.gov/nshmp/).

5.1. Site and Model Input

Use the drop-down list to select the USGS national seismic hazard model (NSHM). Information about the models is customizable at the bottom of the worksheet. Use dynamic data from the USGS Earthquake Hazard Toolbox, when available, because it is the most up-to-date model, and enter the version number.

Use the drop-down list to select the source type such as total, fault, fault cluster, fault system, grid, interface, slab, or zone. The source types are customizable at the bottom of the worksheet, and not all source types will be applicable to a given site based on the drop-down list in the USGS Earthquake Hazard Toolbox.

The latitude and longitude of the site of interest are user-specified input. When entering the longitude, a minus sign must precede the input if it is west of the prime meridian (e.g., locations in the United States). Conditional formatting applies an orange background if a user-specified latitude or longitude input is outside the range of applicability for the selected model at the bottom of the worksheet, and a warning message is displayed. The site and model input are illustrated in Figure 8.

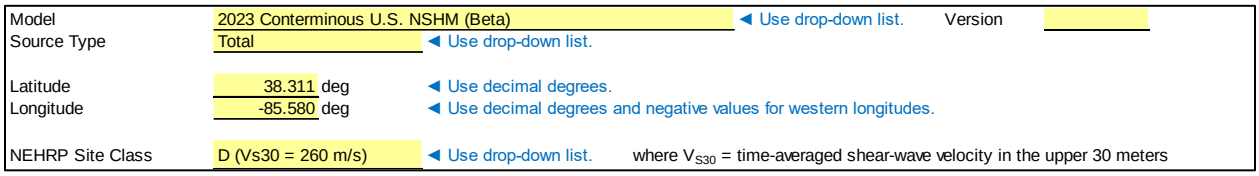

Figure 8. Modern NSHM worksheet: Site and model input.

Use the drop-down list to select the NEHRP site class (FEMA 2020). The RMC Site Classification Toolbox, part of the RMC Seismic Hazard Suite, helps assess the site class. Table 1 presents the eight site classes available to select for modern datasets in the USGS Earthquake Hazard Toolbox as a function of small-strain shear wave velocity in the upper 30 meters (100 feet) (V_{s30}).

Table 1
Available site classes for modern datasets.

Site Class	V_{S30} (m/s)	V_{S30} (ft/s)
A/B	1,500	5,000
B	1,080	3,500
B/C	760	2,500
C	530	1,800
C/D	365	1,200
D	260	850
D/E	185	600
E	150	500

5.2. Hazard Curve Input

The ground motion (GM) and corresponding annual frequency of exceedance (AFE) are obtained from the USGS Earthquake Hazard Toolbox. Values for up to twenty-two ground motion intensity measures, excluding peak ground velocity (PGV), can be exported from the USGS Earthquake Hazard Toolbox as a comma-separated values (CSV) file, a text file format that uses commas to separate values. Figure 9 is an example of hazard curve data as it appears in the USGS Earthquake Hazard Toolbox, and Figure 10 is an example of the same data in Excel from the exported CSV file.

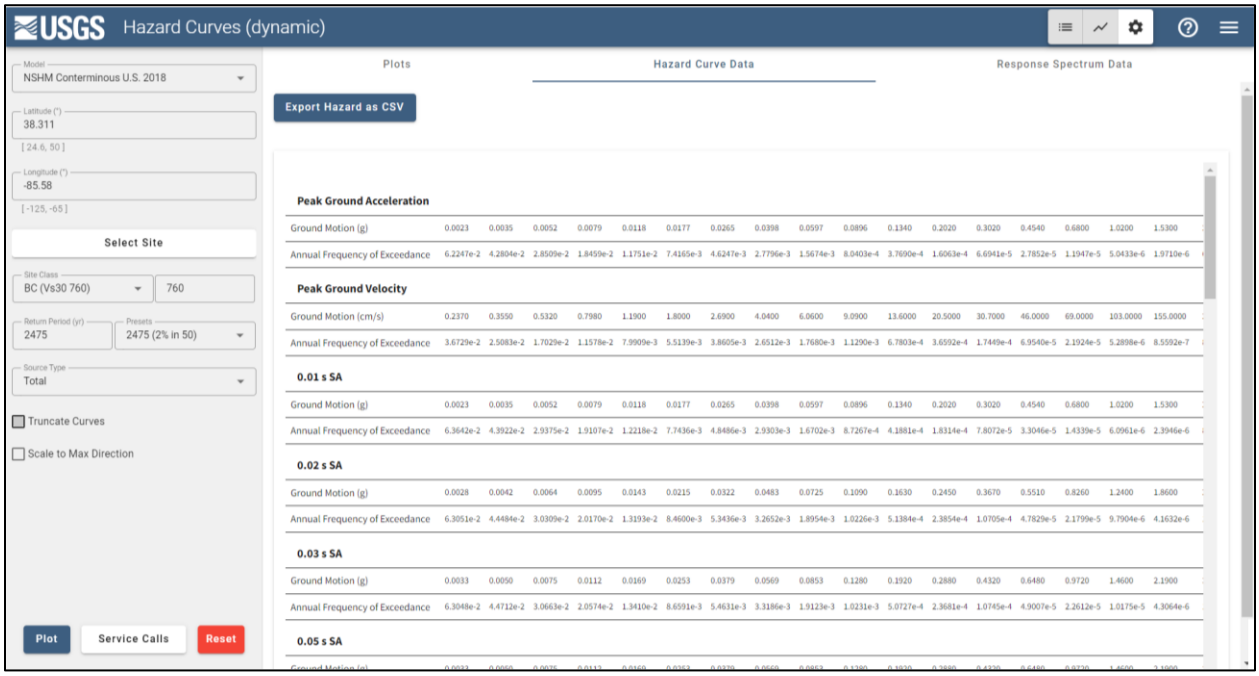

Figure 9. Modern NSHM worksheet: USGS Earthquake Hazard Toolbox hazard curve data.

Peak Ground Acceleration																				
Ground Motion (g)	0.0023	0.0035	0.0052	0.0079	0.0118	0.0177	0.0265	0.0398	0.0597	0.0896	0.134	0.202	0.302	0.454	0.68	1.02	1.53	2.3	3.44	5.17
Annual Frequency of Exceedance	6.22E-02	4.28E-02	2.85E-02	1.85E-02	1.18E-02	7.42E-03	4.62E-03	2.78E-03	1.57E-03	8.04E-04	3.77E-04	1.61E-04	6.69E-05	2.79E-05	1.19E-05	5.04E-06	1.97E-06	6.68E-07	1.90E-07	4.16E-08
Peak Ground Velocity																				
Ground Motion (cm/s)	0.237	0.355	0.532	0.798	1.19	1.8	2.69	4.04	6.06	9.09	13.6	20.5	30.7	46	69	103	155	233	349	525
Annual Frequency of Exceedance	3.67E-02	2.51E-02	1.70E-02	1.16E-02	7.99E-03	5.51E-03	3.86E-03	2.65E-03	1.77E-03	1.13E-03	6.78E-04	3.66E-04	1.74E-04	6.95E-05	2.19E-05	5.29E-06	8.56E-07	8.13E-08	6.61E-09	9.60E-10
0.01 s SA																				
Ground Motion (g)	0.0023	0.0035	0.0052	0.0079	0.0118	0.0177	0.0265	0.0398	0.0597	0.0896	0.134	0.202	0.302	0.454	0.68	1.02	1.53	2.3	3.44	5.17
Annual Frequency of Exceedance	6.36E-02	4.39E-02	2.94E-02	1.91E-02	1.22E-02	7.74E-03	4.85E-03	2.93E-03	1.67E-03	8.73E-04	4.19E-04	1.83E-04	7.81E-05	3.30E-05	1.43E-05	6.10E-06	2.39E-06	8.14E-07	2.32E-07	5.05E-08
0.02 s SA																				
Ground Motion (g)	0.0028	0.0042	0.0064	0.0095	0.0143	0.0215	0.0322	0.0483	0.0725	0.109	0.163	0.245	0.367	0.551	0.826	1.24	1.86	2.79	4.18	6.27
Annual Frequency of Exceedance	6.31E-02	4.45E-02	3.03E-02	2.02E-02	1.32E-02	8.46E-03	5.34E-03	3.27E-03	1.90E-03	1.02E-03	5.14E-04	2.39E-04	1.07E-04	4.78E-05	2.18E-05	9.79E-06	4.16E-06	1.59E-06	5.27E-07	1.43E-07
0.03 s SA																				
Ground Motion (g)	0.0033	0.005	0.0075	0.0112	0.0169	0.0253	0.0379	0.0569	0.0853	0.128	0.192	0.288	0.432	0.648	0.972	1.46	2.19	3.28	4.92	7.38
Annual Frequency of Exceedance	6.30E-02	4.47E-02	3.07E-02	2.06E-02	1.34E-02	8.66E-03	5.46E-03	3.32E-03	1.91E-03	1.02E-03	5.07E-04	2.37E-04	1.07E-04	4.90E-05	2.26E-05	1.02E-05	4.31E-06	1.64E-06	5.34E-07	1.42E-07

Figure 10. Modern NSHM worksheet: Exported hazard curve data as CSV file.

Copy GM-AFE data for each ground motion intensity measure of interest and paste as values in the appropriate cells. Clear any existing GM and AFE data from cells with a light-yellow background so that residual data does not remain after pasting values. Figure 11 is an example of the pasted GM and AFE data and calculated AEP.

Ground Motion Intensity Measure	Peak Ground Acceleration																			
GM (g)	0.0023	0.0035	0.0052	0.0079	0.0118	0.0177	0.0265	0.0398	0.0597	0.0896	0.1340	0.2020	0.3020	0.4540	0.6800	1.0200	1.5300	2.3000	3.4400	5.1700
AFE	6.22E-02	4.28E-02	2.85E-02	1.85E-02	1.18E-02	7.42E-03	4.62E-03	2.78E-03	1.57E-03	8.04E-04	3.77E-04	1.61E-04	6.69E-05	2.79E-05	1.19E-05	5.04E-06	1.97E-06	6.68E-07	1.90E-07	4.16E-08
AEP	6.03E-02	4.19E-02	2.81E-02	1.83E-02	1.17E-02	7.39E-03	4.61E-03	2.78E-03	1.57E-03	8.04E-04	3.77E-04	1.61E-04	6.69E-05	2.79E-05	1.19E-05	5.04E-06	1.97E-06	6.68E-07	1.90E-07	4.16E-08
Ground Motion Intensity Measure	0.01-second Spectral Acceleration																			
GM (g)	0.0023	0.0035	0.0052	0.0079	0.0118	0.0177	0.0265	0.0398	0.0597	0.0896	0.1340	0.2020	0.3020	0.4540	0.6800	1.0200	1.5300	2.3000	3.4400	5.1700
AFE	6.36E-02	4.39E-02	2.94E-02	1.91E-02	1.22E-02	7.74E-03	4.85E-03	2.93E-03	1.67E-03	8.73E-04	4.19E-04	1.83E-04	7.81E-05	3.30E-05	1.43E-05	6.10E-06	2.39E-06	8.14E-07	2.32E-07	5.05E-08
AEP	6.17E-02	4.30E-02	2.89E-02	1.89E-02	1.21E-02	7.71E-03	4.84E-03	2.93E-03	1.67E-03	8.72E-04	4.19E-04	1.83E-04	7.81E-05	3.30E-05	1.43E-05	6.10E-06	2.39E-06	8.14E-07	2.32E-07	5.05E-08
Ground Motion Intensity Measure	0.02-second Spectral Acceleration																			
GM (g)	0.0028	0.0042	0.0064	0.0095	0.0143	0.0215	0.0322	0.0483	0.0725	0.1090	0.1630	0.2450	0.3670	0.5510	0.8260	1.2400	1.8600	2.7900	4.1800	6.2700
AFE	6.31E-02	4.45E-02	3.03E-02	2.02E-02	1.32E-02	8.46E-03	5.34E-03	3.27E-03	1.90E-03	1.02E-03	5.14E-04	2.39E-04	1.07E-04	4.78E-05	2.18E-05	9.79E-06	4.16E-06	1.59E-06	5.27E-07	1.43E-07
AEP	6.11E-02	4.35E-02	2.99E-02	2.00E-02	1.31E-02	8.42E-03	5.33E-03	3.26E-03	1.89E-03	1.02E-03	5.14E-04	2.39E-04	1.07E-04	4.78E-05	2.18E-05	9.79E-06	4.16E-06	1.59E-06	5.27E-07	1.43E-07
Ground Motion Intensity Measure	0.03-second Spectral Acceleration																			
GM (g)	0.0033	0.0050	0.0075	0.0112	0.0169	0.0253	0.0379	0.0569	0.0853	0.1280	0.1920	0.2880	0.4320	0.6480	0.9720	1.4600	2.1900	3.2800	4.9200	7.3800
AFE	6.30E-02	4.47E-02	3.07E-02	2.06E-02	1.34E-02	8.66E-03	5.46E-03	3.32E-03	1.91E-03	1.02E-03	5.07E-04	2.37E-04	1.07E-04	4.90E-05	2.26E-05	1.02E-05	4.31E-06	1.64E-06	5.34E-07	1.42E-07
AEP	6.11E-02	4.37E-02	3.02E-02	2.04E-02	1.33E-02	8.62E-03	5.45E-03	3.31E-03	1.91E-03	1.02E-03	5.07E-04	2.37E-04	1.07E-04	4.90E-05	2.26E-05	1.02E-05	4.31E-06	1.64E-06	5.34E-07	1.42E-07

Figure 11. Modern NSHM worksheet: Hazard curve input.

USGS provides AFE; however, risk assessments need the annual exceedance probability (AEP). The AFE is the number of times the ground motion is exceeded each year, and for very low ground motions, it may be above unity if a ground motion is exceeded multiple times each year. As the AFE becomes less than unity, the frequency of exceedance becomes analogous to a probability, becoming nearly equal to the AEP for frequencies less than approximately 1/100. Generally, structural performance and incremental risk are driven by these less frequent events, and there is little practical difference between AEP and AFE. The toolbox adjusts the AFE values so subsequent calculations use probabilities. The relationship between AEP and AFE is provided as Equation 1.

$$AEP = 1 - e^{-AFE} \tag{1}$$

Plots of GM as a function of AEP for the user-specified site class are at the bottom of the worksheet as illustrated in Figure 12.

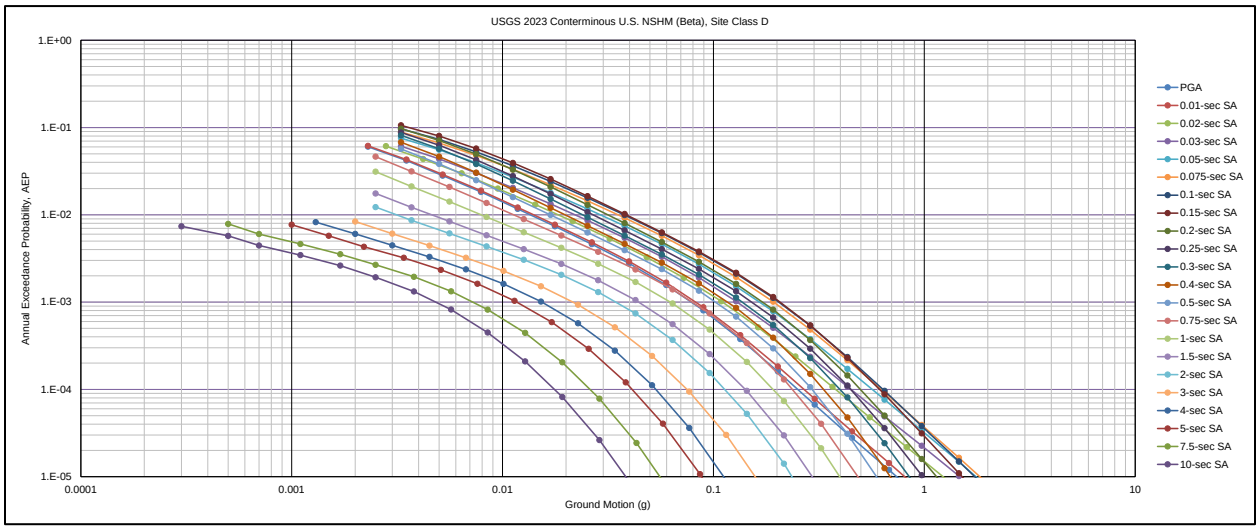

Figure 12. Modern NSHM worksheet: Hazard curve plot.

6. Legacy NSHM

The Legacy NSHM worksheet facilitates the importing and processing of USGS legacy datasets. Two options, discussed in sections 6.2 and 6.3, are provided, depending on the applicable data source.

6.1. Site and Model Input

Use the drop-down list to select the data source as either "USGS Earthquake Hazard Toolbox" or "USGS Gridded Hazard Curve Data File." Use the drop-down list to select the USGS NSHM. Information about the models for each data source is customizable at the bottom of the worksheet.

The input for site coordinates is the same as for the Modern NSHM worksheet. Ensure the site coordinates for short-term NSHM match the input for the corresponding long-term NSHM on the Modern NSHM worksheet.

The NEHRP site class is not user-specified because only NEHRP site class boundary B/C is available for legacy datasets. The site and model input are illustrated in Figure 13

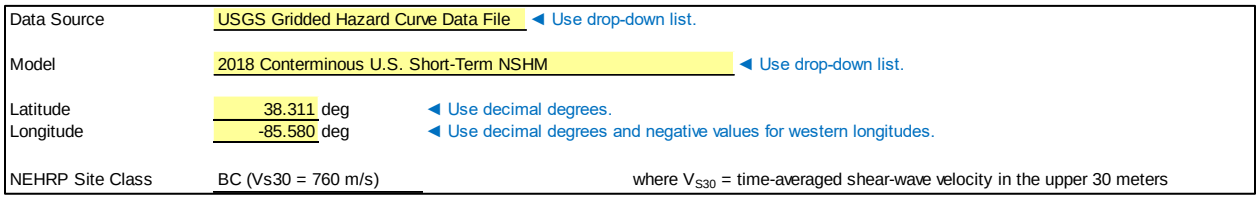

Figure 13. Legacy NSHM worksheet: Site and model input.

6.2. USGS Earthquake Hazard Toolbox

Option 1 processes hazard curve data from the USGS Earthquake Hazard Toolbox. The GM and AFE input are the same as the NSHM Modern worksheet but for PGA, 0.2-second SA, and 1-second SA only. Conditional formatting applies a gray background to this option if "USGS Gridded Hazard Curve Data File" is selected for the data source.

6.3. Hazard Curve Input

Option 2 processes hazard curve data from USGS gridded hazard curve data files. Conditional formatting applies a gray background to this option if "USGS Earthquake Hazard Toolbox" is selected for the data source.

The ground motion (GM) and corresponding annual frequency of exceedance (AFE) are obtained from files containing gridded seismic hazard curve data (https://www.usgs.gov/programs/earthquake-hazards/seismic-hazard-model-maps-and-site-specific-data). Download the archive (.zip file) from the ScienceBase Catalog to obtain the gridded data for the hazard curves. Each archive contains a READ_ME.txt file that provides a detailed description of the files.

Each gridded data file has a row of constant GM values that must be copied from the gridded data file and pasted as values in the appropriate location on the worksheet. All other rows contain AFE values for every latitude-longitude pair based on the grid spacing and geographic limits of the selected model. The

user-specified site coordinates are bounded by the coordinates of a square grid (latitude-longitude pairs). The AFE values for each of the four coordinate pairs must be copied from the gridded data file and pasted as values in the appropriate location on the worksheet. Detailed instructions on how to open the files and find the four coordinate pairs to import are at the top of the worksheet.

Figure 14 illustrates how the four coordinate pairs are displayed for each ground motion intensity measure. If incorrect AFE data is pasted from the gridded data file for any of the four pairs, conditional formatting applies an orange background to the incorrect longitude or latitude, and a warning message is displayed as illustrated in Figure 14. If this occurs, return to the gridded data file and select the correct data. For some legacy datasets, it may be necessary to reverse the order of the latitude and longitude columns so longitude appears first. Repeat this import procedure for each ground motion intensity measure: PGA, 0.2-second SA, and 1-second SA.

Ground Motion Intensity Measure Peak Ground Acceleration

Search	Latitude	Longitude		Latitude	Longitude	0.0050	0.0070	0.0098	0.0137
Pair 1	38.35	-85.60	Invalid data entry ►	35.65	-97.40	1.8009E+00	1.5516E+00	1.2794E+00	1.0118E+00
Pair 2	38.35	-85.55	Invalid data entry ►	35.65	-97.35	1.7921E+00	1.5427E+00	1.2718E+00	1.0066E+00
Pair 3	38.30	-85.60	Invalid data entry ►	35.60	-97.40	1.7827E+00	1.5308E+00	1.2576E+00	9.9044E-01
Pair 4	38.30	-85.55	Invalid data entry ►	35.60	-97.35	1.7737E+00	1.5218E+00	1.2498E+00	9.8511E-01

Figure 14. Legacy NSHM worksheet: Hazard curve input for latitude-longitude pairs.

Because the user-specified coordinates are bounded by the coordinates of a square grid (latitude-longitude pairs) based on the grid spacing of the selected model, a series of three linear interpolations estimates the hazard curve for the user-specified coordinates, as Figure 15 illustrates.

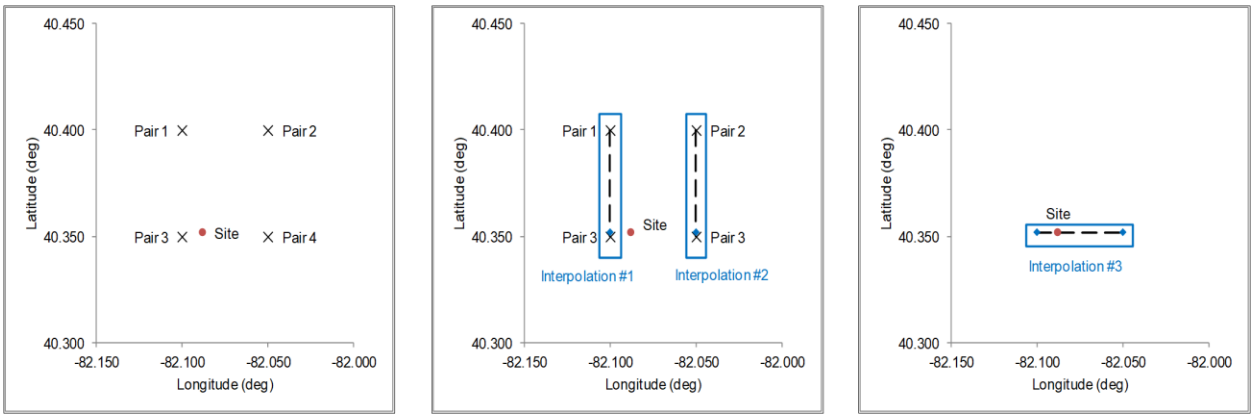

Figure 15. Legacy NSHM worksheet: Example of interpolating hazard curve data for a site.

The AEP is calculated from the interpolated AFE as on the Modern NSHM worksheet.

Plots of GM as a function of AEP for NEHRP site class boundary B/C are at the bottom of the worksheet as illustrated in Figure 16.

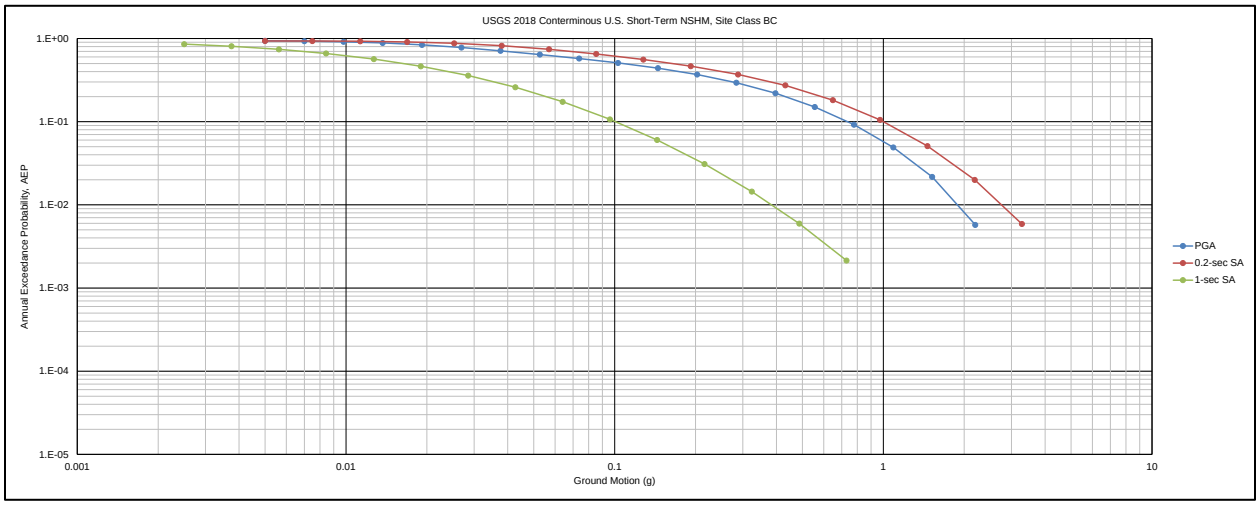

Figure 16. Legacy NSHM worksheet: Hazard curve plot.

7. Site Class Effects

The Site Class Effects worksheet modifies the ground motions from legacy datasets for site class effects because they are only available for NEHRP site class boundary B/C.

7.1. Site Class

In step 1, use the drop-down list to select the NEHRP site class according to ASCE/SEI 7-16 as Figure 17 illustrates. The RMC Site Classification Toolbox, part of the RMC Seismic Hazard Suite, helps assess the site class. Table 2 provides the available site classes for the general procedures for site class adjustment in ASCE/SEI 7-16 used to modify the ground motions for site class effects. Ensure the selected NEHRP site class is consistent with the value selected on Modern NSHM worksheet.

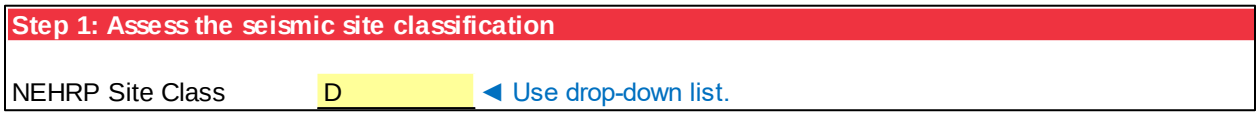

Figure 17. Step 1 of Site Class Effects worksheet: Site class input.

Table 2
Site classification (ASCE/SEI 7-16).

Site Class	$\overline{v_s}$ (ft/s)	$\overline{N}$ or $\overline{N_{ch}}$ (bpf)	$\overline{s_u}$ (psf)
A. Hard rock	$\overline{v_s}$ > 5,000	N/A	N/A
B. Rock	2,500 < $\overline{v_s}$ ≤ 5,000	N/A	N/A
C. Very dense soil and soft rock	1,200 < $\overline{v_s}$ ≤ 2,500	$\overline{N}$ or $\overline{N_{ch}}$ > 50	$\overline{s_u}$ > 2,000
D. Stiff soil	600 ≤ $\overline{v_s}$ ≤ 1,200	15 ≤ $\overline{N}$ or $\overline{N_{ch}}$ ≤ 50	1,000 ≤ $\overline{s_u}$ ≤ 2,000
E. Soft clay	$\overline{v_s}$ < 600	$\overline{N}$ or $\overline{N_{ch}}$ < 15	$\overline{s_u}$ < 1,000
	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf

7.2. Adjusted Ground Motions

In step 2, the general procedures in ASCE/SEI 7-16 are used to adjust the NEHRP site class boundary B/C hazard curves for the user-specified site class.

If a short-term NSHM is selected for the model on the Legacy NSHM worksheet, the return period to truncate the short-term hazard curves is input as Figure 18 illustrates. Otherwise, conditional formatting applies a gray background to this input. The short-term (one-year) forecasts must not be applied for very low rates of exceedance because hazard estimates from induced earthquakes are not compatible with estimates of long-term seismic hazard caused by tectonic processes. Therefore, the mean seismic hazard curves are truncated at this user-specified return period.

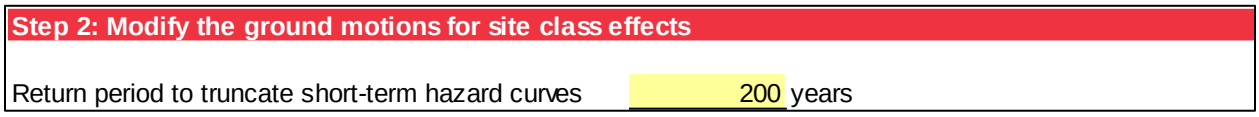

Figure 18. Step 2 of Site Class Effects worksheet: Return period input for short-term NSHM.

The general procedures in ASCE/SEI 7-16 are used to adjust the NEHRP site class boundary B/C hazard curves for USGS legacy datasets. The ground motions for PGA, 0.2-second SA (S_S), and 1-second SA (S_1) are multiplied by the site coefficients in ASCE/SEI 7-16 to adjust for the user-specified site class to obtain the modified PGA (PGA_M), 0.2-second SA (S_{MS}), and 1-second SA (S_{M1}) used on the Hazard Curves worksheet, as shown in Equations 2, 3, and 4.

$$PGA_M = F_{PGA} PGA \quad (2)$$

$$S_{MS} = F_a S_S \quad (3)$$

$$S_{M1} = F_v S_1 \quad (4)$$

where:

F_{PGA} = PGA site coefficient
F_a = short-period site coefficient
F_v = long-period (1-second SA) site coefficient

The coefficients to adjust for site class effects in ASCE/SEI 7-16 depend on the ground motion levels for soil sites because of non-linear response at higher ground motions. Therefore, site class coefficients are linearly interpolated for intermediate ground motion levels as indicated in ASCE/SEI 7-16. Table 3 through Table 5 provide the site coefficients from ASCE/SEI 7-16.

Table 3
Site coefficient, F_{PGA}.

Site Class	PGA (g)					
	≤0.1	0.2	0.3	0.4	0.5	≥0.6
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.2	1.2	1.2	1.2	1.2
D	1.6	1.4	1.3	1.2	1.1	1.1
E	2.4	1.9	1.6	1.4	1.2	1.1

Table 4
Short-period site coefficient, F_a.

Site Class	S_S (g)					
	≤0.25	0.5	0.75	1.0	1.25	≥1.5
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	1.2*	1.2*	1.2*

*NOTE: Values for Site Class C were used for Site Class E with S_S greater than or equal to 1.0g, as indicated by the exception in Section 11.4.8 of ASCE/SEI 7-16.

Table 5
Long-period site coefficient, F_v.

Site Class	S_1 (g)					
	≤ 0.1	0.2	0.3	0.4	0.5	≥0.6
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2	2.0	1.9	1.8	1.7
E	4.2	4.2*	4.2*	4.2*	4.2*	4.2*

NOTE: Values for Site Class E with S_1 greater than 0.1g are not provided in ASCE/SEI 7-16. Use with great caution.

ASCE/SEI 7-16 does not provide F_v values for Site Class E with S_1 greater than 0.1g. The toolbox uses the F_v value of 4.2 for S_1 less than or equal to 0.1g for S_1 greater than 0.1g to perform the calculations. Conditional formatting applies an orange background to cells for F_v and S_{M1} for S_1 greater than 0.1g as a warning.

Figure 19 is an example of the ground motions modified for site class effects for legacy short-term datasets.

Step 2: Modify the ground motions for site class effects

Return period to truncate short-term hazard curves 200 years

Ground Motion Intensity Measure Peak Ground Acceleration

PGA (g)	0.005	0.007	0.0098	0.0137	0.0192	0.0269	0.0376	0.0527	0.0738	0.103	0.145	0.203	0.284	0.397	0.556	0.778	1.09	1.52	2.2	#N/A
F_{PGA}	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.59	1.51	1.40	1.32	1.20	1.10	1.10	1.10	1.10	1.10	#N/A
PGA_M (g)	0.008	0.011	0.016	0.022	0.031	0.043	0.060	0.084	0.118	0.164	0.219	0.284	0.374	0.478	0.612	0.856	1.199	1.672	2.420	#N/A
AEP	9.37E-01	9.30E-01	9.13E-01	8.83E-01	8.38E-01	7.78E-01	7.11E-01	6.42E-01	5.74E-01	5.09E-01	4.40E-01	3.69E-01	2.94E-01	2.20E-01	1.50E-01	9.21E-02	4.90E-02	2.17E-02	5.75E-03	#N/A

Ground Motion Intensity Measure 0.2-second Spectral Acceleration

S_S (g)	0.005	0.0075	0.0113	0.0169	0.0253	0.038	0.057	0.0854	0.128	0.192	0.288	0.432	0.649	0.973	1.46	2.19	3.28	#N/A	#N/A	#N/A
F_a	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.57	1.45	1.28	1.11	1.00	1.00	1.00	#N/A	#N/A	#N/A
S_{MS} (g)	0.008	0.012	0.018	0.027	0.040	0.061	0.091	0.137	0.205	0.307	0.452	0.628	0.831	1.081	1.460	2.190	3.280	#N/A	#N/A	#N/A
AEP	9.34E-01	9.33E-01	9.26E-01	9.08E-01	8.75E-01	8.19E-01	7.42E-01	6.52E-01	5.58E-01	4.65E-01	3.69E-01	2.73E-01	1.81E-01	1.05E-01	5.09E-02	2.00E-02	5.89E-03	#N/A	#N/A	#N/A

Ground Motion Intensity Measure 1-second Spectral Acceleration

S_1 (g)	0.0025	0.00375	0.00563	0.00844	0.0127	0.019	0.0285	0.0427	0.0641	0.0961	0.144	0.216	0.324	0.487	0.73	#N/A	#N/A	#N/A	#N/A	#N/A
F_v	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.31	2.17	1.98	1.81	1.70	#N/A	#N/A	#N/A	#N/A	#N/A
S_{M1}	0.006	0.009	0.014	0.020	0.030	0.046	0.068	0.102	0.154	0.231	0.333	0.468	0.640	0.883	1.241	#N/A	#N/A	#N/A	#N/A	#N/A
AEP	8.54E-01	8.06E-01	7.41E-01	6.60E-01	5.65E-01	4.63E-01	3.58E-01	2.60E-01	1.73E-01	1.07E-01	6.02E-02	3.10E-02	1.44E-02	5.95E-03	2.14E-03	#N/A	#N/A	#N/A	#N/A	#N/A

Figure 19. Step 2 of Site Class Effects worksheet: Modified ground motions.

Plots of GM as a function of AEP for the user-specified site class are at the bottom of the worksheet as illustrated in Figure 20.

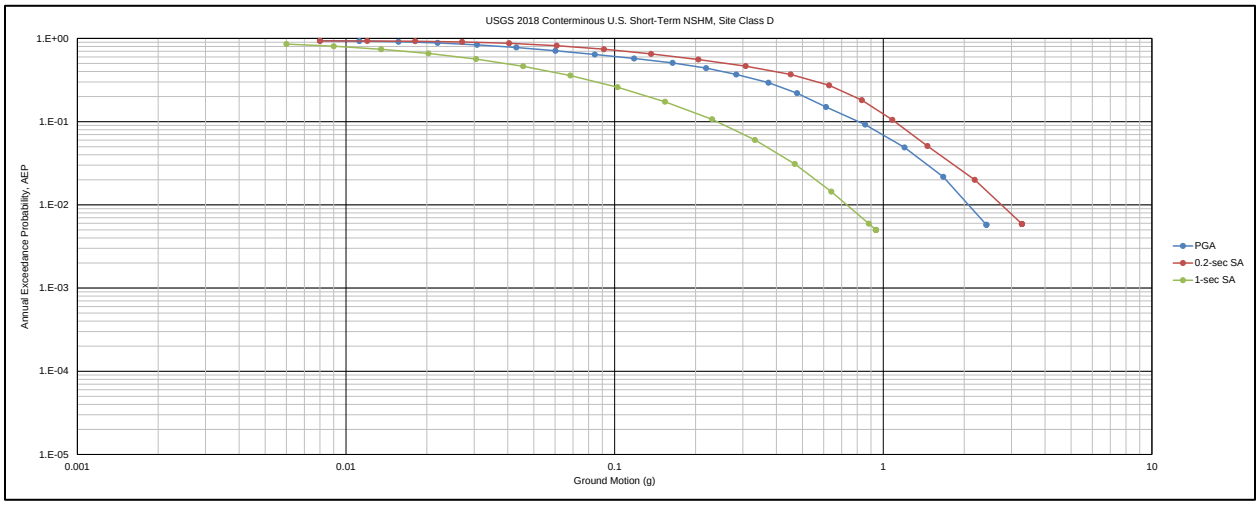

Figure 20. Step 2 of Site Class Effects worksheet: Hazard curve plot.

8. Site-Specific Data

The Site-Specific Data worksheet is for probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA) data developed for the site for comparison against the USGS hazard curves.

8.1. Probabilistic Seismic Hazard Analysis

In step 1, the PSHA input must be enabled or disabled. If a site-specific PSHA is not available, select "No" from the drop-down list so that any residual input data for the site-specific PSHA is not used (Figure 21). Conditional formatting then applies a gray background.

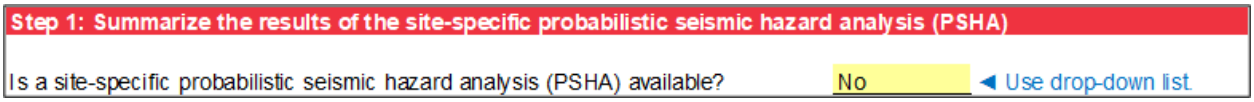

Figure 21. Step 1 of Site-Specific Data worksheet: Disable PSHA input.

If a site-specific PSHA is available, select "Yes" from the drop-down list to enable the PSHA input (Figure 22). Additional input includes adding the author and completion date for the site-specific PSHA and selecting the NEHRP Site Class from the drop-down list. A site-specific PSHA may have been completed for a v_{s30} other than those listed in the drop-down list; however, for comparison to the USGS hazard curves, the nearest v_{s30} should be selected. The input generates the series names that appear in the legend for the hazard curves.

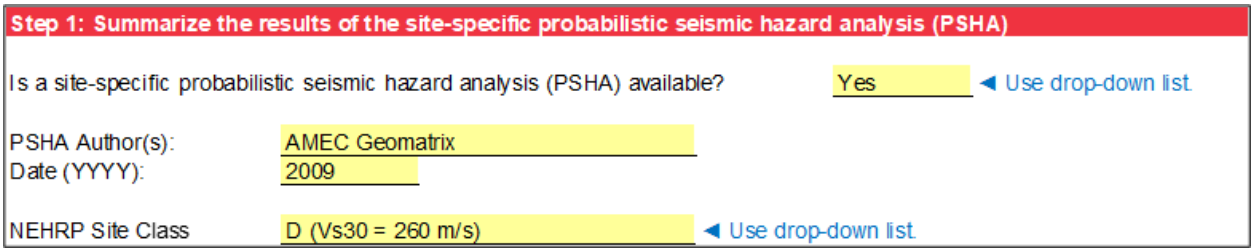

Figure 22. Step 1 of Site-Specific Data worksheet: Enable PSHA input.

Up to five site-specific hazard curves may be inputted. AFE is the assumed input, which is converted to AEP as previously described. If a data file is available for the site-specific PSHA, both the ground motions and AFE must be copied from the data file and pasted as values (Figure 23). PGA, 0.2-second SA, and 1-second SA are fixed selections to facilitate comparison to USGS seismic hazard curves. Up to two additional SAs can be evaluated. Each curve can contain a maximum of 20 data points.

Ground Motion Intensity Measure	PGA					Series name on Hazard Curves worksheet				PSHA mean hazard curve for PGA, Site Class D (AMEC Geomatrix 2009)							
PGA (g)	0.0010	0.0100	0.0200	0.0500	0.0700	0.1000	0.2000	0.3000	0.4000	0.5000	0.7000	1.0000	2.0000	3.0000			
AFE	1.03E+00	4.14E-01	2.46E-01	1.06E-01	7.31E-02	4.59E-02	1.44E-02	6.49E-03	3.47E-03	1.96E-03	6.57E-04	1.56E-04	4.99E-06	4.24E-07			
AEP	6.44E-01	3.39E-01	2.18E-01	1.01E-01	7.05E-02	4.49E-02	1.43E-02	6.47E-03	3.46E-03	1.96E-03	6.56E-04	1.56E-04	4.99E-06	4.24E-07	-	-	-
Ground Motion Intensity Measure	0.2 -sec SA					Series name on Hazard Curves worksheet				PSHA mean hazard curve for 0.2-sec SA, Site Class D (AMEC Geomatrix 2009)							
SA (g)																	
AFE																	
AEP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ground Motion Intensity Measure	1.0 -sec SA					Series name on Hazard Curves worksheet				PSHA mean hazard curve for 1-sec SA, Site Class D (AMEC Geomatrix 2009)							
SA (g)	0.0010	0.0100	0.0200	0.0500	0.0700	0.1000	0.2000	0.3000	0.4000	0.5000	0.7000	1.0000	2.0000	3.0000			
AFE	1.19E+00	3.95E-01	2.31E-01	1.05E-01	7.53E-02	5.00E-02	1.82E-02	8.74E-03	4.91E-03	3.04E-03	1.37E-03	5.13E-04	4.27E-05	6.67E-06			
AEP	6.96E-01	3.27E-01	2.06E-01	1.00E-01	7.25E-02	4.87E-02	1.80E-02	8.71E-03	4.90E-03	3.03E-03	1.37E-03	5.13E-04	4.27E-05	6.67E-06	-	-	-

Figure 23. Step 1 of Site-Specific Data worksheet: Site-specific PSHA input.

8.2. Deterministic Seismic Hazard Analysis

In step 2, the DSHA input must be enabled or disabled. If a site-specific DSHA is not available, select "No" from the drop-down list so that any residual input data for the site-specific DSHA is not used (Figure 24). Conditional formatting then applies a gray background.

Figure 24. Step 2 of Site-Specific Data worksheet: Disable DSHA input.

If a site-specific DSHA is available, select "Yes" from the drop-down list to enable the DSHA input. Additional input includes adding the author and completion date for the site-specific DSHA (Figure 25).

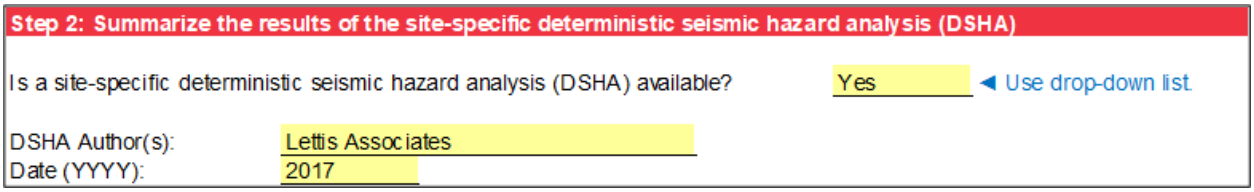

Figure 25. Step 2 of Site-Specific Data worksheet: Enable DSHA input.

While any number of DSHA response spectra can be developed for a site, it is common practice to develop two response spectra: a nearby source that is representative of the short-period hazard and a more distant source that is representative of the long-period hazard. Therefore, up to two DSHA spectra may be inputted. Since the intent is for DSHA spectra to be plotted as information along with the PSHA hazard curves, ground motions for the same five spectral periods used for the site-specific PSHA may be inputted. The developer of the DSHA must decide what epsilon value (i.e., number of standard deviations about the median) to use for the ground motion prediction equation (GMPE). The most common values are 0 (the median, which equals the 50th percentile envelope) and 1 (the median plus one standard deviation, which equals the 84th percentile envelope). Using the drop-down list to select the percentile generates the series names that appear as vertical reference lines on the hazard curves plot.

After inputting the response spectrum values, the AEP of each ground motion level is interpolated from site-specific PSHA hazard curves, if available, in step 1. The AEP values are interpolated using the z-variate scale for AEP and the logarithmic scale for ground motion and rounded to three significant digits. The AEP is a convenient reference for the user but must be carefully interpreted. Although the DSHA ground motion is specific to a particular source, the AEP is for all sources included in the PSHA.

If a site-specific PSHA is not available, conditional formatting adds a gray background to cells that do not apply. Figure 26 and Figure 27 illustrate the two scenarios.

Source 1	M7.1 Puente Hills at 8.1 km		Percentile	50th ◄ Use drop-down list for percentile.
GM Intensity Measure	Ground Motion (g)	AEP (total mean hazard)	RP (yr)	Series Name on Hazard Curves worksheet
PGA	0.661	7.97E-04	1,255	DSHA for PGA (50th percentile) M7.1 Puente Hills at 8.1 km
0.2 -sec SA	1.200	-	-	DSHA for 0.2-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
1.0 -sec SA	0.763	1.09E-03	919	DSHA for 1-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
0.3 -sec SA	1.285	1.03E-03	974	DSHA for 0.3-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
- -sec SA		-	-	DSHA for --sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
Source 2	M8.2 Some Large Regional Source at 52 km		Percentile	50th ◄ Use drop-down list for percentile.
GM Intensity Measure	Ground Motion (g)	AEP (total mean hazard)	RP (yr)	Series Name on Hazard Curves worksheet
PGA	0.300	6.47E-03	154	DSHA for PGA (50th percentile) M8.2 Some Large Regional Source at 52 km
0.2 -sec SA	0.500	-	-	DSHA for 0.2-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
1.0 -sec SA	1.000	5.13E-04	1,948	DSHA for 1-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
0.3 -sec SA	0.550	8.95E-03	111	DSHA for 0.3-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
- -sec SA		-	-	DSHA for --sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km

Figure 26. Step 2 of Site-Specific Data worksheet: DSHA input with site-specific PSHA.

Source 1	M7.1 Puente Hills at 8.1 km		Percentile	50th ◄ Use drop-down list for percentile.
GM Intensity Measure	Ground Motion (g)	AEP (total mean hazard)	RP (yr)	Series Name on Hazard Curves worksheet
PGA	0.661	-	-	DSHA for PGA (50th percentile) M7.1 Puente Hills at 8.1 km
0.2 -sec SA	1.200	-	-	DSHA for 0.2-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
1.0 -sec SA	0.763	-	-	DSHA for 1-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
0.3 -sec SA	1.285	-	-	DSHA for 0.3-sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
- -sec SA		-	-	DSHA for --sec SA (50th percentile) M7.1 Puente Hills at 8.1 km
Source 2	M8.2 Some Large Regional Source at 52 km		Percentile	50th ◄ Use drop-down list for percentile.
GM Intensity Measure	Ground Motion (g)	AEP (total mean hazard)	RP (yr)	Series Name on Hazard Curves worksheet
PGA	0.300	-	-	DSHA for PGA (50th percentile) M8.2 Some Large Regional Source at 52 km
0.2 -sec SA	0.500	-	-	DSHA for 0.2-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
1.0 -sec SA	1.000	-	-	DSHA for 1-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
0.3 -sec SA	0.550	-	-	DSHA for 0.3-sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km
- -sec SA		-	-	DSHA for --sec SA (50th percentile) M8.2 Some Large Regional Source at 52 km

Figure 27. Step 2 of Site-Specific Data worksheet: DSHA input without site-specific PSHA.

9. Hazard Curves

The Hazard Curves worksheet provides summary tables of ground motions for user-specified return periods and plots selected hazard curves.

9.1. Summary Tables

Use the drop-down list to characterize the USGS long-term dataset as either Modern or Legacy.

Use the drop-down to indicate whether to include the short-term (one-year) forecast for induced seismicity in the conterminous U.S. (CONUS) along with the CONUS long-term dataset. Conditional formatting applies a gray background to the cells if a CONUS long-term dataset is not selected on the Modern NSHM worksheet or a CONUS short-term dataset is not selected on the Legacy NSHM worksheet.

Summary tables for PGA, 0.2-second SA, and 1-second SA ground motions containing up to eight user-specified return periods (RPs), shown in Figure 28, can be generated. The ground motions are interpolated using the logarithmic scale for ground motion and the z-variate scale for AEP and rounded to three significant digits.

For modern long-term datasets, the NEHRP site class is obtained from the Modern NSHM worksheet. For site-specific PSHA, the NEHRP site class is obtained from the Site-Specific Data worksheet. For legacy long-term datasets, the NEHRP site class is obtained from the Site Class Effects worksheet. Figure 28 illustrates ground motions for PGA from modern long-term datasets when induced seismicity is not included.

Summary Tables for Common Return Periods

RP (yr)	PGA (g), Site Class D			
	USGS (2023)	Site-Specific PSHA (-)	USGS Short-Term (-)	USGS (-)
145	0.0189	-	-	-
225	0.0274	-	-	-
475	0.0486	-	-	-
975	0.0775	-	-	-
2,475	0.129	-	-	-
10,000	0.252	-	-	-
	-	-	-	-
	-	-	-	-

Figure 28. Hazard Curves worksheet: Summary table for PGA for long-term dataset.

For modern CONUS long-term datasets when induced seismicity is included, the NEHRP site class is obtained from the Modern NSHM worksheet and labeled LT (long term) followed by the NEHRP site class for the CONUS short-term datasets labeled ST (short term) from the Site Class Effects worksheet because the site class could be slightly different based on the available options on those worksheets.

Figure 29 illustrates ground motions for PGA from modern long-term datasets when induced seismicity is included.

Summary Tables for Common Return Periods

RP (yr)	PGA (g), Site Class D (LT) and D (ST)			
	USGS (2023)	Site-Specific PSHA (-)	USGS Short-Term (2018)	USGS (-)
145	0.0189	-	2.31	-
225	0.0274	-	-	-
475	0.0486	-	-	-
975	0.0775	-	-	-
2,475	0.129	-	-	-
10,000	0.252	-	-	-
	-	-	-	-
	-	-	-	-

Figure 29. Hazard Curves worksheet: Summary table for PGA for long-term and short-term datasets.

The first ground motion column in Figure 28 and Figure 29 summarizes the results for USGS modern long-term datasets if "Modern" is selected from the drop-down list at the top of the worksheet. The model year and ground motions are obtained from the Modern NSHM worksheet.

The second ground motion column summarizes the results for a site-specific PSHA if available. The model year and ground motions are obtained from the Site-Specific Data worksheet.

The third ground motion column summarizes the results for USGS legacy short-term (induced seismicity) datasets if a CONUS long-term dataset is selected on the Modern NSHM worksheet and a CONUS short-term dataset is selected on the Legacy NSHM worksheet. The model year is obtained from the Legacy NSHM worksheet, and the ground motions are obtained from the Site Class Effects worksheet. Ground motions display only for return periods less than the user-specified value for truncation on the Site Class Effects NSHM worksheet since the results must not be applied for very low AEP.

The fourth ground motion column summarizes the results for USGS legacy long-term datasets if "Legacy" is selected from the drop-down list at the top of the worksheet. The model year is obtained from the Legacy NSHM worksheet, and the ground motions are obtained from the Site Class Effects worksheet.

9.2. Hazard Curves

The hazard curves for the modern long-term datasets, legacy short-term datasets if induced seismicity is applicable, site-specific PSHA if applicable, and legacy long-term datasets are displayed. Figure 30 shows that by selecting the chart and then selecting the filter icon to display the filter pane, the data series for display can be selected. This is useful when computing the results from multiple ground motion intensity measures, but not all are applicable or desired to display. Resize or move the legend box within the chart area for legibility based on the selected hazard curves. Delete data series for DSHA from legend, if applicable, because their label appears adjacent to the plotted vertical reference line.

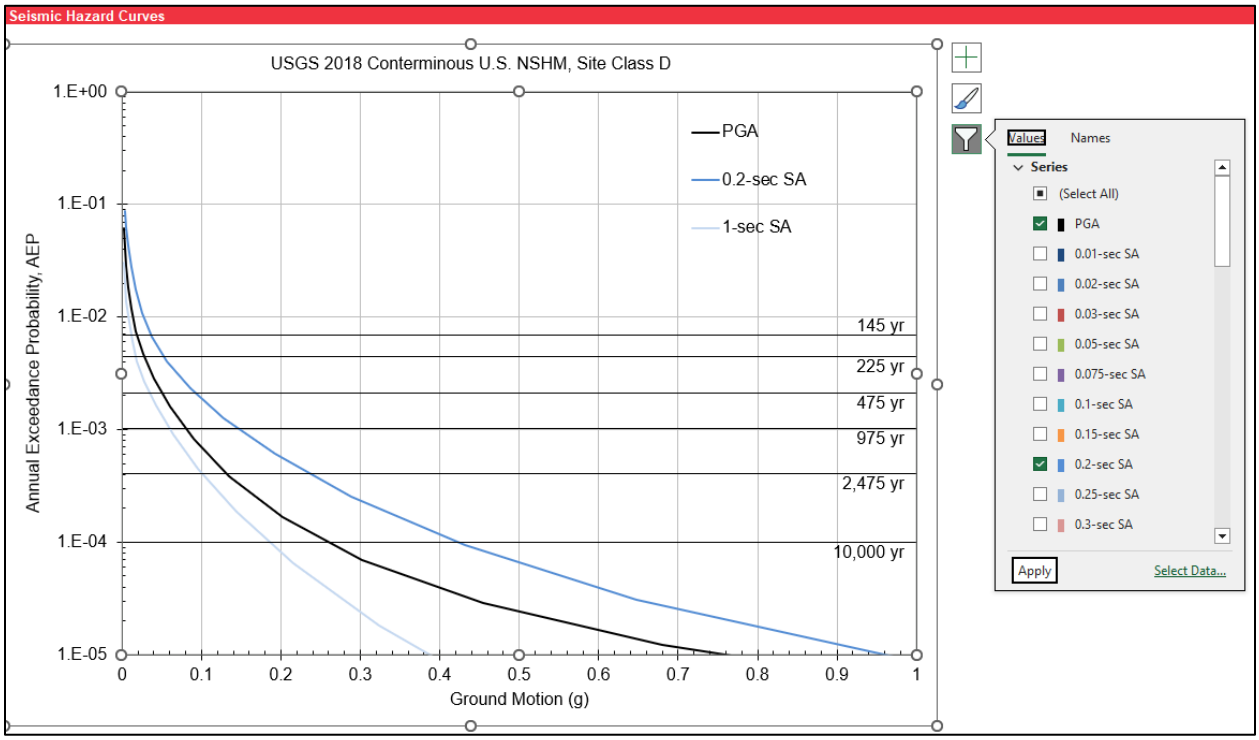

Figure 30. Hazard Curves worksheet: Filtering data series for hazard curves.

Figure 31 illustrates the plot options for the above chart. The maximum and minimum values for the primary y-axis (AEP) and maximum value for the x-axis (ground motion) are user-specified. Up to eight horizontal reference lines can be displayed based on the user-specified return period in the summary tables.

Worksheet	Hazard Curves		
◄ Select the chart with a left-click of mouse in plot area.			
Select the Filters icon	to toggle which series (critical gradient) to plot; then hit Apply.		
y-axis bounds			
maximum	1.00E+00	◄ Enter maximum AEP.	Value Primary Max: 1
minimum	1.00E-05	◄ Enter minimum AEP.	Value Primary Min: 0.00001
x-axis bounds			
minimum	0.0		Category Primary Min: 0
maximum	1.0	◄ Enter maximum ground motion.	Category Primary Max: 1

Figure 31. Hazard Curves worksheet: Plot options for hazard curves.

10. References

American Society of Civil Engineers (ASCE). (2017). *Minimum design loads and associated criteria for buildings and other structures* (ASCE/SEI 7-16). https://doi.org/10.1061/9780784414248.

Federal Emergency Management Agency (FEMA). (2020). *NEHRP recommended seismic provisions for new buildings and other structures* (FEMA P-2082-1). https://www.fema.gov/sites/default/files/2020-10/fema_2020-nehrp-provisions_part-1-and-part-2.pdf.

Petersen, M.D., Mueller, C.S., Moschetti, M.P., Hoover, S.M., Rukstales, K.S., McNamara, D.E., Williams, R.A., Shumway, A.M., Powers, P.M., Earle, P.S., Llenos, A.L., Michael, A.J., Rubinstein, J.L., Norbeck, J.H., and Cochran, E.S. (2018). *Data release for 2018 one-year seismic hazard forecast for the central and eastern United States from induced and natural earthquakes*. U.S. Geological Survey data release. https://doi.org/10.5066/F7Cf9PC4.

Petersen, M.D., Shumway, A.M., Powers, P.M., Mueller, C.S., Moschetti, M.P., Frankel, A.D., Rezaeian, S., McNamara, D.E., Luco, N., Boyd, O.S., Rukstales, K.S., Jaiswal, K.S., Thompson, E.M., Hoover, S.M., Clayton, B.S., Field, E.H., and Zeng, Y. (2020). The 2018 update of the U.S. National Seismic Hazard Model: Overview of model and implications. *Earthquake Spectra 36*(1), 5–41. https://doi.org/10.1177/8755293019878199.

Appendix A. Acronym List

AEP	Annual Exceedance Probability
AFE	Annual Frequency of Exceedance
ASCE	American Society of Civil Engineers
CEUS	Central and Eastern United States
CONUS	Conterminous United States
CPD	Computer Program Document
DSHA	Deterministic Seismic Hazard Analysis
FEMA	Federal Emergency Management Agency
GM	Ground Motion
GMPE	Ground Motion Prediction Equation
HEC	Hydrologic Engineering Center
IWR	Institute for Water Resources
LT	Long Term
NEHRP	National Earthquake Hazards Reduction Program
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PSHA	Probabilistic Seismic Hazard Analysis
QC	Quality Control
RMC	Risk Management Center
RP	Return Period
SA	Spectral Acceleration
ST	Short Term
SEI	Structural Engineering Institute
UDF	User-Defined Function

U.S.	United States
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development
USGS	United States Geological Survey