UrbanFootprint

TECHNICAL DOCUMENTATION

UrbanFootprint Earthquake Methodology

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Overview

An earthquake is the sudden shaking of the Earth's surface caused by the release of energy from the Earth's crust. This energy release typically happens due to the movement of tectonic plates, generating seismic waves that travel through the Earth. Earthquakes can vary in strength and length, potentially causing significant damage to buildings, infrastructure, and the environment and posing serious risks to human safety.

Understanding earthquake probability across the United States helps anticipate and mitigate potential threats to the built environment and communities. Proactive risk management based on accurate hazard predictions protects physical assets and supports sustainable development.

Earthquakes are measured using various scales and methods to assess their magnitude, intensity, and other characteristics. Some examples include magnitude scales, intensity scales, seismograph measurements, peak ground velocity (PGV), and peak ground acceleration (PGA). Peak ground acceleration (PGA) is a measure of the intensity of ground shaking at a specific location. It represents the highest acceleration recorded during an earthquake and is typically expressed in terms of gravity (g), where 1 g is equivalent to the acceleration due to Earth's gravity (approximately 9.8 m/s^2). It provides a quantitative measure of how strongly the ground shakes during an earthquake; higher values indicate more intense shaking.

The authoritative agency on earthquake hazard is the U.S. Geological Survey (USGS). USGS provides probabilistic seismic hazard curves and uniform-hazard ground motion values calculated for a grid of points with a spacing of 0.2 degrees in latitude and longitude over the contiguous U.S. (CONUS) and Alaska (AK) using the 2023 National Seismic Hazard Model (NSHM) and with a spacing of 0.02 degrees over Hawaii using the 2021 NSHM.

USGS provides hazard curve data representing National Earthquake Hazards Reduction Program (NEHRP) Site Classes A/B to E. A NEHRP Site Class is a classification of the time-averaged shear-wave velocity of the top 30 meters of soil (Vs30). It is a key index adopted by the earthquake engineering community to account for seismic site conditions. Vs30 values and ranges are mapped to eight different Site Classes (Table 1).

Table 1: Vs30 Site Class Mapping

NEHRP Site Class	Vs30 Value Associated	Vs30 Range Associated
A	-	> 1500

AB	1,500 m/s	1315-1500
B	1,080 m/s	945-1315
BC	760 m/s	660-945
C	530 m/s	460-660
CD	365 m/s	315-460
D	260 m/s	225-315
DE	185 m/s	180-225
E	150 m/s	< 180

We use a machine learning-derived Vs30 map of CONUS (Geyin & Maurer, 2022) to determine the Site Class of each pixel, and use the corresponding hazard curves to linearly interpolate the annual probability of experiencing each Peak Ground Acceleration (PGA) threshold: 18%, 34% and 65%g. The PGA thresholds of 18%, 34%, and 65%g are based on the ranges of PGAs associated with “Moderate”, “Moderate/Heavy” and “Heavy” potential damage categories.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: Earthquake Magnitude, Energy Release, and Shaking Intensity

Source Data

2023 U.S. 50-State National Seismic Hazard Model

USGS published probabilistic seismic hazard curves on a 0.2 x 0.2 degree grid over CONUS and Alaska.

- ➔ **Source:** U.S Geological Survey (USGS)
- ➔ **Link:** Hazard curves for the conterminous U.S. and Alaska for the 2023 National Seismic Hazard Model

2021 Update of the U.S. National Seismic Hazard Model for Hawaii

USGS published probabilistic seismic hazard curves on a 0.02 x 0.02 degree grid over Hawaii.

- ➔ **Source:** U.S Geological Survey (USGS)

➔ **Link:** Hazard curves for Hawaii for the 2021 Update of the U.S. National Seismic Hazard Model

U.S. National Vs30 Maps Informed by Remote Sensing and Machine Learning

A machine learning-derived Vs30 map (Geyin & Maurer, 2022) on a 220 x 220 meter grid over CONUS.

➔ **Source:** Geyin & Maurer, 2022
➔ **Link:** Geyin & Maurer, 2022

H3 Geospatial Indexing System

➔ **Source:** Uber Technologies, Inc.
➔ **Link:** H3 Geospatial Indexing System

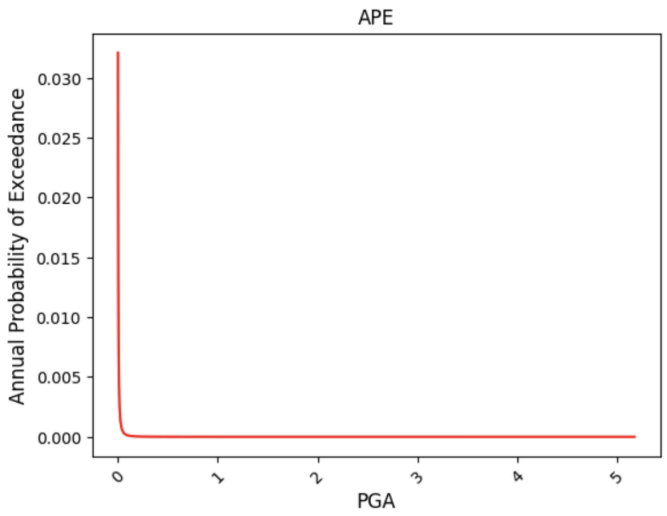
Methodology

We resampled the machine learning-derived Vs30 map onto H3 grids at Zoom Level 9, which is the most similar H3 resolution to the source data (220m x 220m). Using the Vs30 data, we assigned a NEHRP Site Class to each H3 cell corresponding to the Vs30 value. The Vs30 data only exists over CONUS, so in Alaska and Hawaii, we fall back to Site Class 'BC' because that is the Site Class that USGS uses as the National Seismic Hazard Map. When an H3 cell's Vs30 value corresponds to Site Class A, it gets reassigned to AB because USGS did not provide hazard curves for Site Class A, and AB is the next closest Site Class.

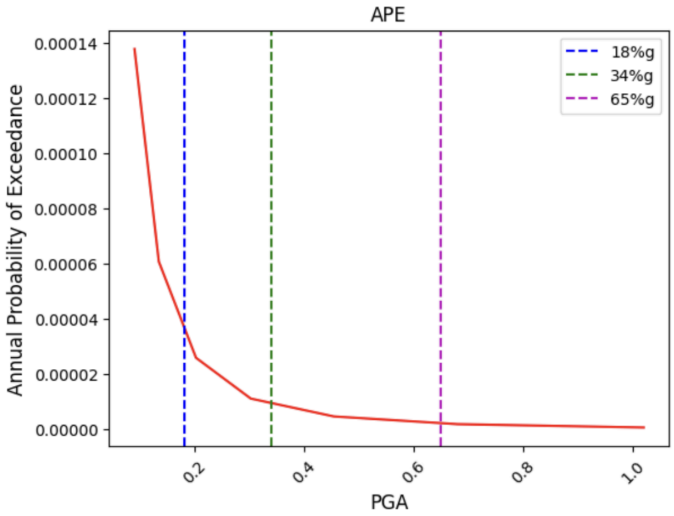
The USGS hazard curve data for all Site Classes were spatially joined onto the Vs30 H3 Zoom Level 9 grids. At each H3 grid, we then had access to the following information: predicted Vs30 value, the corresponding Site Class, and the annual frequency of exceedance for a range of PGAs (0.233%g to 517%g) for all Site Classes (AB to E).

The Annual Frequency of Exceedance (AFE) values provided by the USGS were converted to Annual Probability of Exceedance (APEs) using the formula:
$APE = 1 - e^{-AFE}$.

The range of annual probabilities for PGAs (0.233%g to 517%g) contain the 3 thresholds for which we want to calculate APEs: 18%g, 34%g, and 65%g. We linearly interpolate between data points to get the APE for the exact PGA along the curve that we are interested in.

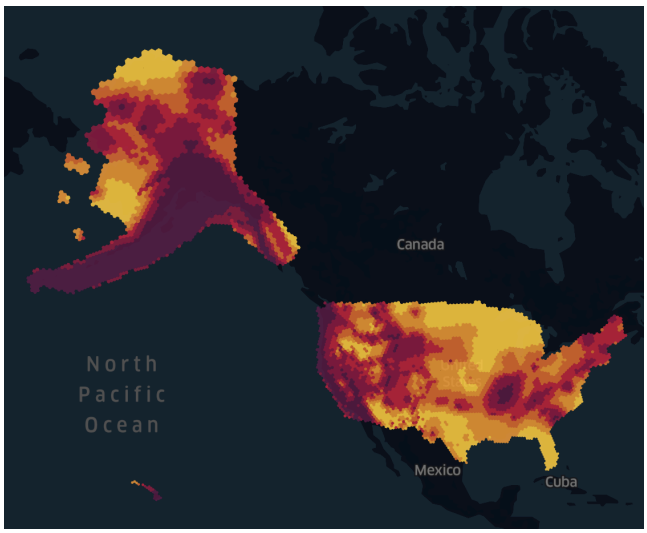


Probability Curve for a single H3 grid for the full range of data (0.233%g → 517%g)

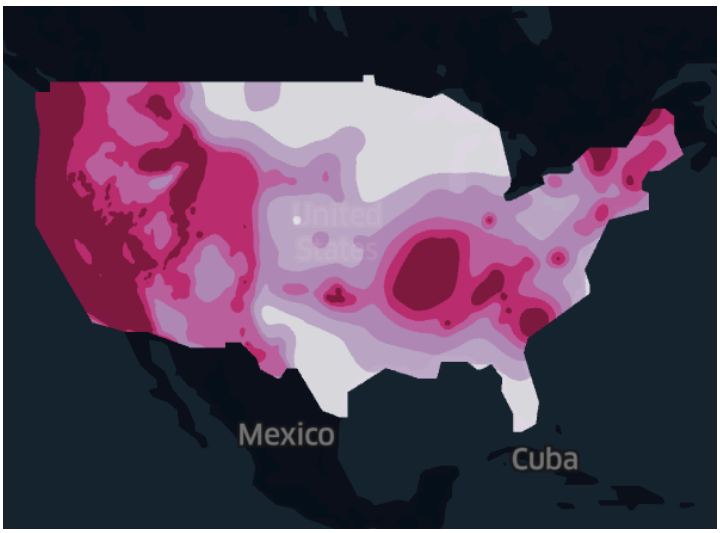


Probability Curve for a single H3 grid zoomed in over the PGA thresholds of interest (18%g, 34%g and 65%g)

The interpolation is done for every single H3 grid across CONUS, Alaska and Hawaii, resulting in annual probabilities of exceedance of 3 PGA thresholds based on the predicted NEHRP Site Class.



Annual probability of exceedance of a PGA of 34%g (shown at H3 zoom 4, though we deliver UrbanFootprint Insights at H3 zoom 9)



USGS NSHM: PGA w/ a 2% chance of exceedance in 50 years for NEHRP Site Class BC