A Predictive Earthquake Damage Model written in Python

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The Earthquake Damage Model predicts damages to structures in near-real time following earthquakes in the USA using nationwide building centroids and Hazus damage functions.

Hazus is a risk model for earthquakes, floods tsunamis and hurricanes and is the authoritative voice for predicted impacts following one of these major events. To learn more about Hazus, you can read about it directly from the Hazus program's website.

This blog post describes in further detail the methodology and supplemental data sets used in the Earthquake Damage Model, which is available in GitHub here. The model is a Python program that can be set up to run regularly as a scheduled task, in which case it could provide predicted structural damage following an earthquake in near-real time.

Data and Tables:

There are several important data sources used in this predictive model. Any required tables are available in the GitHub repo, however some of the external data sets must either be downloaded and/or generated by the user with some basic geoprocessing steps, which are outlined in the GitHub readme file.

Building Centroids: In order to try and predict the number of buildings damaged in an area following an earthquake, you first need to know how many buildings are present. I used Oak Ridge National Labs building outlines from the USA Structures project. Some other open and public data sets that could be used instead are Microsoft Building Footprints or OpenStreetMap.

General Building Stock (GBS): This is the Census Tract-level breakdown of structure types. Not only do you need to calculate how many buildings are within each Tract, but you need to be able to estimate what kinds of structures they are. This information was extracted from Hazus at the Tract-level.

Hazus Earthquake Model Structure Types:

No	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	W1	Wood, light frame (<5000 sq.ft.)		All	1	14
2	W2	Wood (>5000 sq.ft.)		All	2	24
3	S1L	Steel Moment Frame	LR	1-3	2	24
4	S1M		MR	4-7	5	60
5	S1H		HR	8+	13	156
6	S2L	Steel Braced Frame	LR	1-3	2	24
7	S2M		MR	4-7	5	60
8	S2H		HR	8+	13	156
9	S3	Steel Light Frame		All	1	15
10	S4L	Steel Frame with Cast-in-Place Concrete Shear Walls	LR	1-3	2	24
11	S4M		MR	4-7	5	60
12	S4H		HR	8+	13	156
13	S5L	Steel Frame with Unreinforced Masonry Infill Walls	LR	1-3	2	24
14	S5M		MR	4-7	5	60
15	S5H		HR	8+	13	156
16	C1L	Concrete Moment Frame	LR	1-3	2	20
17	C1M		MR	4-7	5	50
18	C1H		HR	8+	12	120
19	C2L	Concrete Shear Walls	LR	1-3	2	20
20	C2M		MR	4-7	5	50
21	C2H		HR	8+	12	120
22	C3L	Concrete Frame with Unreinforced Masonry Infill Walls	LR	1-3	2	20
23	C3M		MR	4-7	5	50
24	C3H		HR	8+	12	120
25	PC1	Precast Concrete Tilt-Up Walls		All	1	15
26	PC2L	Precast Concrete Frame with Concrete Shear Walls	LR	1-3	2	20
27	PC2M		MR	4-7	5	50
28	PC2H		HR	8+	12	120
29	RM1L	Reinforced Masonry Bearing Walls /w Wood or Metal Deck Diaphragms	LR	1-3	2	20
30	RM1M		MR	4+	5	50
31	RM2L	Reinforced Masonry Bearing Walls /w Precast Concrete Diaphragms	LR	1-3	2	20
32	RM2M		MR	4-7	5	50
33	RM2H		HR	8+	12	120
34	URML	Unreinforced Masonry Bearing Walls	LR	1-2	1	15
35	URMM		MR	3+	3	39
36	MH	Mobile Homes		All	1	12

Sample of Hazus General Building Stock (GBS) indicating the percentage of structures within each Structure Type per Tract:

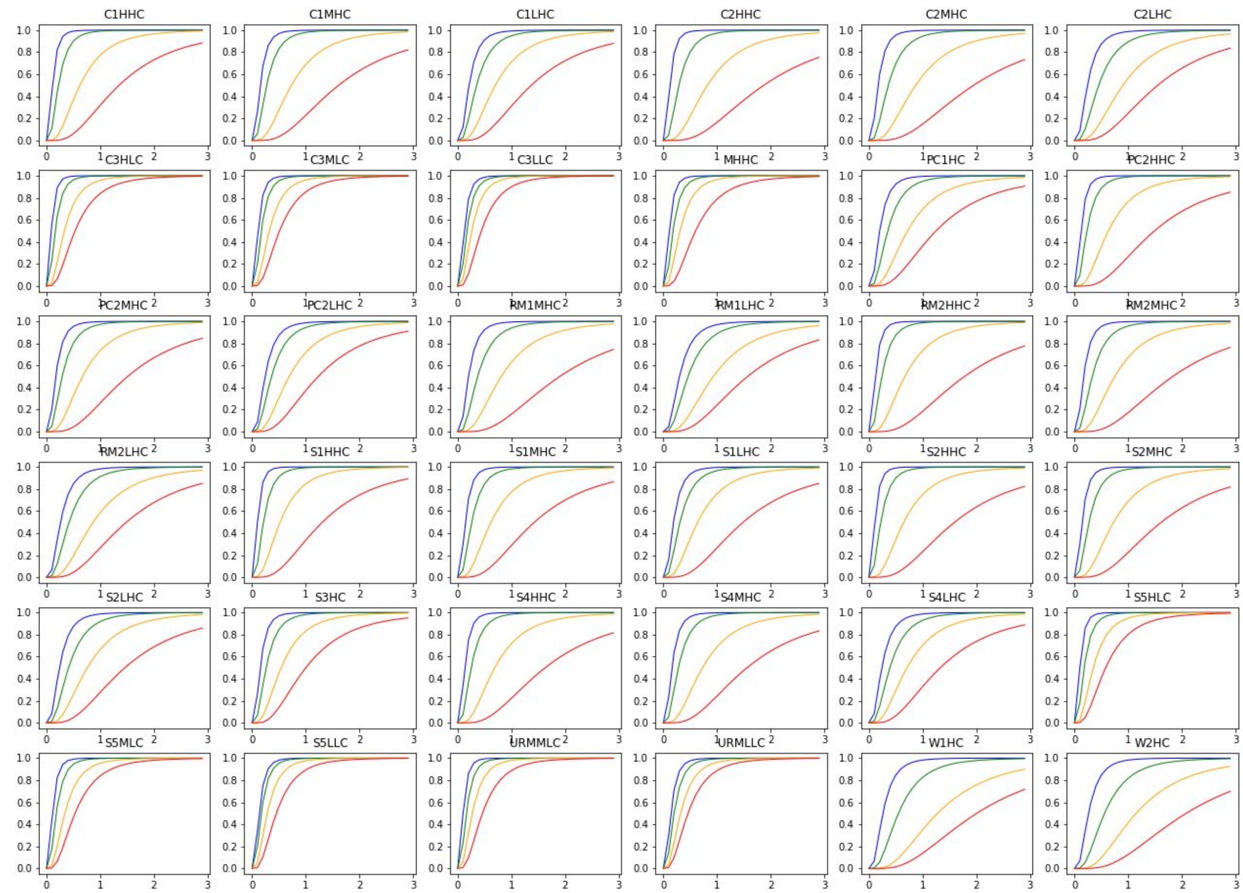
Tract	W1	W2	S1L	S1M	S1H	S2L	S2M	S2H	S3	S4L	S4M	S4H
6001400100	93.12%	1.12%	0.49%	0.00%	0.00%	0.21%	0.00%	0.00%	0.21%	0.28%	0.00%	0.00%
6001400200	88.04%	1.87%	1.00%	0.00%	0.00%	0.37%	0.00%	0.00%	0.37%	0.62%	0.00%	0.00%
6001400300	86.18%	2.08%	0.95%	0.00%	0.00%	0.36%	0.00%	0.00%	0.48%	0.77%	0.00%	0.00%
6001400400	88.71%	1.58%	0.58%	0.00%	0.00%	0.22%	0.00%	0.00%	0.43%	0.72%	0.00%	0.00%
6001400500	87.30%	1.48%	0.56%	0.00%	0.00%	0.28%	0.00%	0.00%	0.65%	0.93%	0.00%	0.00%
6001400600	88.55%	1.07%	0.54%	0.00%	0.00%	0.18%	0.00%	0.00%	0.54%	0.89%	0.00%	0.00%
6001400700	86.18%	1.59%	0.80%	0.00%	0.00%	0.43%	0.00%	0.00%	0.65%	0.94%	0.00%	0.00%
6001400800	81.70%	1.92%	1.31%	0.00%	0.00%	0.61%	0.00%	0.00%	0.71%	1.11%	0.00%	0.00%
6001400900	85.82%	1.28%	0.77%	0.00%	0.00%	0.38%	0.00%	0.00%	0.77%	1.02%	0.00%	0.00%
6001401000	86.63%	1.39%	0.56%	0.00%	0.00%	0.28%	0.00%	0.00%	0.56%	0.84%	0.00%	0.00%
6001401100	75.17%	2.98%	1.54%	0.00%	0.00%	0.58%	0.00%	0.00%	1.06%	1.73%	0.00%	0.00%
6001401200	85.49%	2.13%	0.75%	0.00%	0.00%	0.32%	0.00%	0.00%	0.64%	0.85%	0.00%	0.00%
6001401300	31.28%	14.26%	6.38%	0.00%	0.00%	1.70%	0.00%	0.00%	1.28%	3.40%	0.00%	0.00%
6001401400	78.73%	2.04%	1.07%	0.00%	0.00%	0.43%	0.00%	0.00%	0.97%	1.61%	0.00%	0.00%
6001401500	81.92%	1.98%	1.13%	0.00%	0.00%	0.56%	0.00%	0.00%	0.85%	1.13%	0.00%	0.00%
6001401600	71.50%	3.67%	1.92%	0.00%	0.00%	1.22%	0.00%	0.00%	1.22%	1.57%	0.00%	0.00%
6001401700	74.39%	3.30%	2.00%	0.00%	0.00%	1.22%	0.00%	0.00%	1.04%	1.13%	0.00%	0.00%
6001401800	83.83%	1.14%	0.68%	0.00%	0.00%	0.23%	0.00%	0.00%	0.91%	1.37%	0.00%	0.00%
6001402200	80.03%	2.03%	1.09%	0.00%	0.00%	0.62%	0.00%	0.00%	0.94%	1.40%	0.00%	0.00%
6001402400	79.11%	1.85%	0.92%	0.00%	0.00%	0.55%	0.00%	0.00%	0.92%	1.29%	0.00%	0.00%
6001402500	75.29%	3.04%	1.14%	0.00%	0.00%	0.38%	0.00%	0.00%	0.76%	1.14%	0.00%	0.00%
6001402600	68.03%	4.08%	2.04%	0.00%	0.00%	0.68%	0.00%	0.00%	1.36%	2.04%	0.00%	0.00%
6001402700	72.61%	3.02%	1.76%	0.00%	0.00%	0.75%	0.00%	0.00%	1.01%	1.76%	0.00%	0.00%
6001402800	45.84%	8.32%	4.69%	0.00%	0.00%	1.71%	0.00%	0.00%	1.49%	2.77%	0.00%	0.00%

Tract	S5L	S5M	S5H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	C3M	C3H	PC1	PC2L
6001400100	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%	0.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.77%	0
6001400200	0.00%	0.00%	0.00%	0.25%	0.00%	0.00%	1.87%	0.00%	0.00%	0.12%	0.00%	0.00%	1.25%	0
6001400300	0.00%	0.00%	0.00%	0.30%	0.00%	0.00%	2.20%	0.00%	0.00%	0.12%	0.00%	0.00%	1.31%	0
6001400400	0.00%	0.00%	0.00%	0.22%	0.00%	0.00%	1.94%	0.00%	0.00%	0.14%	0.00%	0.00%	0.93%	0
6001400500	0.00%	0.00%	0.00%	0.19%	0.00%	0.00%	2.41%	0.00%	0.00%	0.19%	0.00%	0.00%	1.02%	0
6001400600	0.00%	0.00%	0.00%	0.18%	0.00%	0.00%	2.15%	0.00%	0.00%	0.18%	0.00%	0.00%	0.89%	0
6001400700	0.00%	0.00%	0.00%	0.22%	0.00%	0.00%	2.53%	0.00%	0.00%	0.22%	0.00%	0.00%	1.16%	0
6001400800	0.00%	0.00%	0.00%	0.30%	0.00%	0.00%	3.34%	0.00%	0.00%	0.20%	0.00%	0.00%	1.92%	0
6001400900	0.00%	0.00%	0.00%	0.13%	0.00%	0.00%	2.81%	0.00%	0.00%	0.26%	0.00%	0.00%	1.15%	0
6001401000	0.00%	0.00%	0.00%	0.22%	0.00%	0.00%	2.34%	0.00%	0.00%	0.17%	0.00%	0.00%	1.11%	0
6001401100	0.00%	0.00%	0.00%	0.58%	0.00%	0.00%	4.72%	0.00%	0.00%	0.29%	0.00%	0.00%	2.12%	0
6001401200	0.00%	0.00%	0.00%	0.32%	0.00%	0.00%	2.45%	0.00%	0.00%	0.21%	0.00%	0.00%	1.39%	0
6001401300	0.00%	0.00%	0.00%	2.13%	0.00%	0.00%	9.57%	0.00%	0.00%	0.43%	0.00%	0.00%	5.96%	1
6001401400	0.00%	0.00%	0.00%	0.43%	0.00%	0.00%	4.40%	0.00%	0.00%	0.32%	0.00%	0.00%	1.83%	0
6001401500	0.00%	0.00%	0.00%	0.42%	0.00%	0.00%	3.39%	0.00%	0.00%	0.14%	0.00%	0.00%	1.84%	0
6001401600	0.00%	0.00%	0.00%	0.52%	0.00%	0.00%	4.72%	0.00%	0.00%	0.35%	0.00%	0.00%	3.85%	1
6001401700	0.00%	0.00%	0.00%	0.52%	0.00%	0.00%	3.82%	0.00%	0.00%	0.17%	0.00%	0.00%	4.17%	0
6001401800	0.00%	0.00%	0.00%	0.23%	0.00%	0.00%	3.64%	0.00%	0.00%	0.46%	0.00%	0.00%	0.68%	0
6001402200	0.00%	0.00%	0.00%	0.31%	0.00%	0.00%	3.74%	0.00%	0.00%	0.31%	0.00%	0.00%	2.18%	0
6001402400	0.00%	0.00%	0.00%	0.37%	0.00%	0.00%	3.70%	0.00%	0.00%	0.37%	0.00%	0.00%	1.29%	0
6001402500	0.00%	0.00%	0.00%	0.38%	0.00%	0.00%	3.42%	0.00%	0.00%	0.38%	0.00%	0.00%	1.90%	0
6001402600	0.00%	0.00%	0.00%	0.68%	0.00%	0.00%	6.12%	0.00%	0.00%	0.68%	0.00%	0.00%	2.72%	1
6001402700	0.00%	0.00%	0.00%	0.50%	0.00%	0.00%	5.03%	0.00%	0.00%	0.25%	0.00%	0.00%	3.27%	1
6001402800	0.00%	0.00%	0.00%	1.49%	0.00%	0.00%	9.59%	0.00%	0.00%	0.21%	0.00%	0.00%	5.76%	1

Damage Function Variables: Hazus damage functions are open and available online. The easiest place to access them, along with a repository of many other peer-reviewed physical vulnerability functions, is through [The OpenQuake Platform](). Hazus' damage functions are a set of cumulative distribution functions whose variables are dependent on structure type and seismic design code. They help to estimate the probability that a structure might meet or exceed

Slight, Moderate, Extensive or Complete damage based on the peak ground acceleration (PGA).

Set of damage functions for each Structure Type + Seismic Design Code. For example, C1HHC can be interpreted as: C1 (Concrete Moment Frame), H (High Rise), HC (High Code). The colored lines represent Damage Curves for the following Damage Categories: Blue — Slight Damage, Green — Moderate Damage, Yellow — Extensive Damage, Red — Complete Damage. For each graph, the X-axis is Peak Ground Acceleration (PGA) (%g), and the Y-axis is Probability of Meeting or Exceeding the Specified Damage State:



[USGS ShakeMap API](#): ShakeMaps provide near-real-time maps of ground motion and shaking intensity following significant earthquakes.

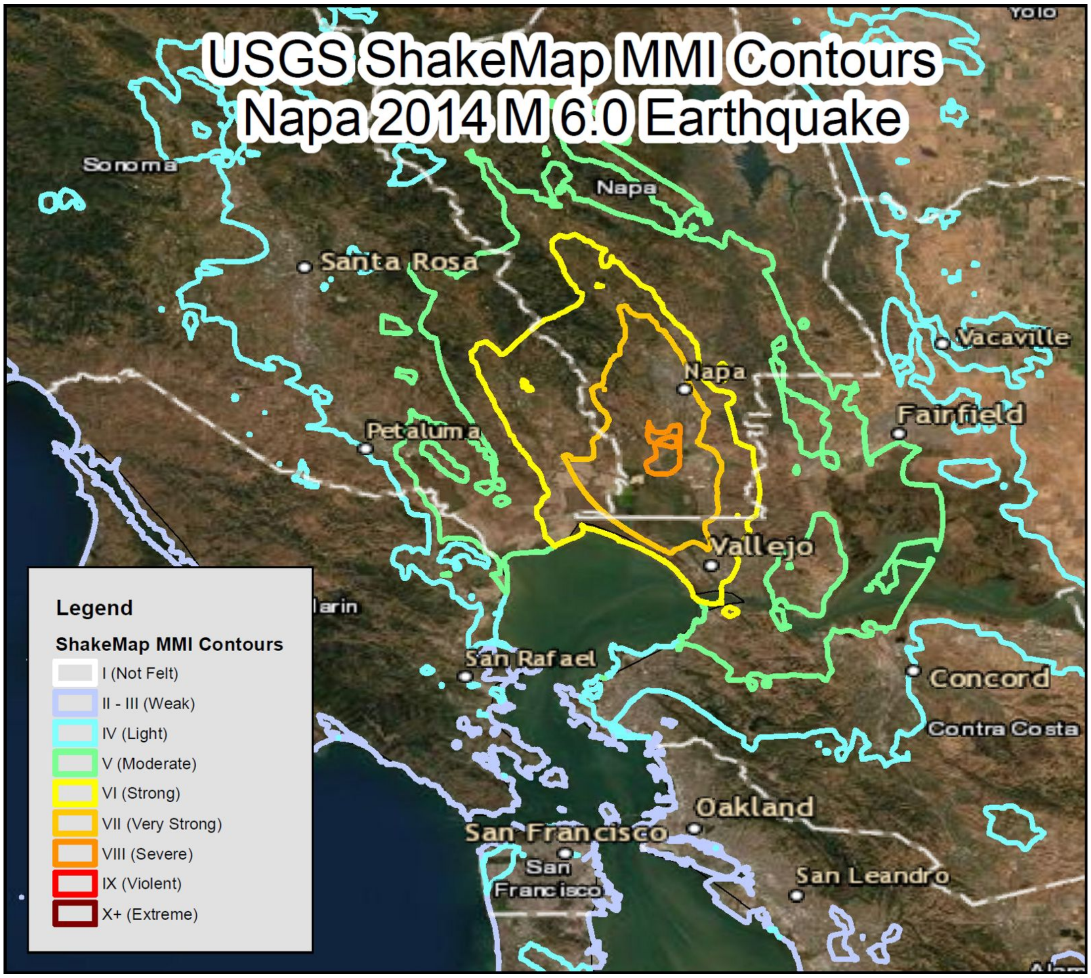
Other supplementary data sets used in the code (for doing things like spatial filtering, spatial joins, etc) include:

- Esri Detailed Counties
- Census TIGER/Line Shapefiles for Counties & Tracts

How the model works:

The program pings the USGS ShakeMap API to detect new or recent earthquake events in the USA. If the earthquake occurred in the US, and GIS files are available through the API, data is downloaded to the ShakeMaps subdirectory.

USGS ShakeMap (MMI) GIS data for the Napa 2014 M 6.0 Earthquake. MMI represents the intensity of ground shaking following an earthquake:

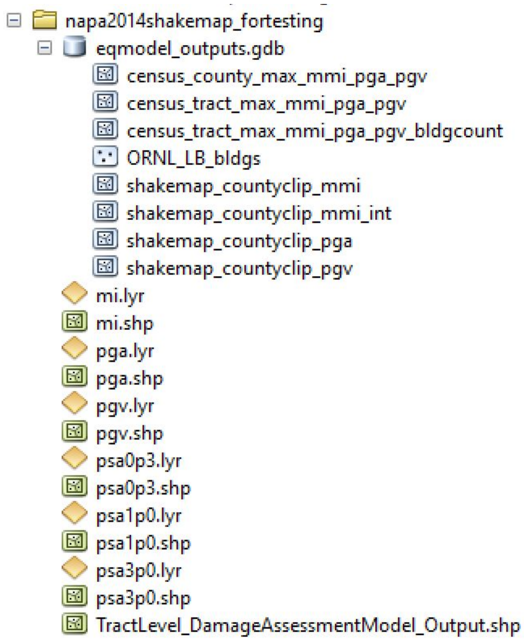


Sometimes following an earthquake, the ShakeMap data will be updated by USGS as the epicenter is relocated or more data comes available. In this case, the program will update the model results based on the most up-to-date ShakeMap data.

The ShakeMap GIS files are then processed and clipped to census geographies (counties, tracts), with all hazard information spatially joined to each Tract, County and building centroid. All output files are saved into a local geodatabase built inside the ShakeMap folder for the event.

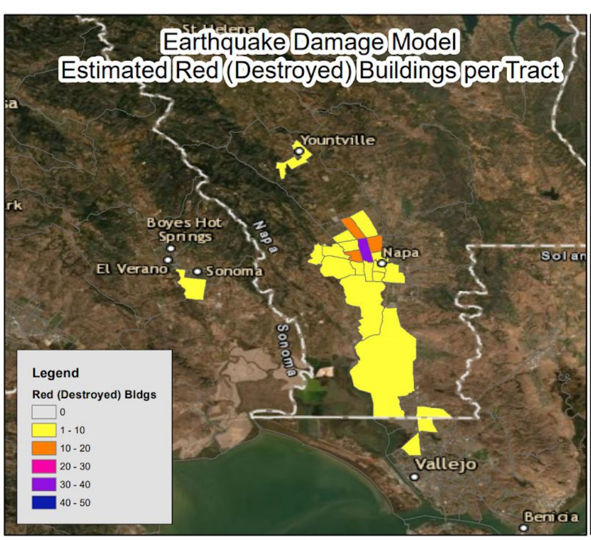
The building centroid count for each tract is used to estimate the number of buildings within each tract, and to calculate the breakdown of structures using the Hazus GBS table. Below is a breakdown of all the files pulled from USGS, as well as the files generated by the Earthquake Damage Model.

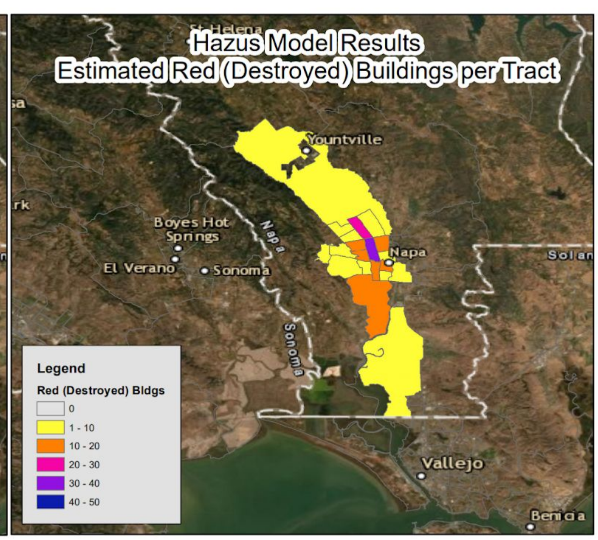
Data sets produced by the Earthquake Damage Model for a single earthquake event:



The final output of the model is the Tract-Level Damage Assessment, which is stored in the *TractLevel_DamageAssessmentModel_Output.shp* file. This contains the number of structures within each Damage Category (Green, Yellow, Red) for each Tract within the spatial extent of the ShakeMap.

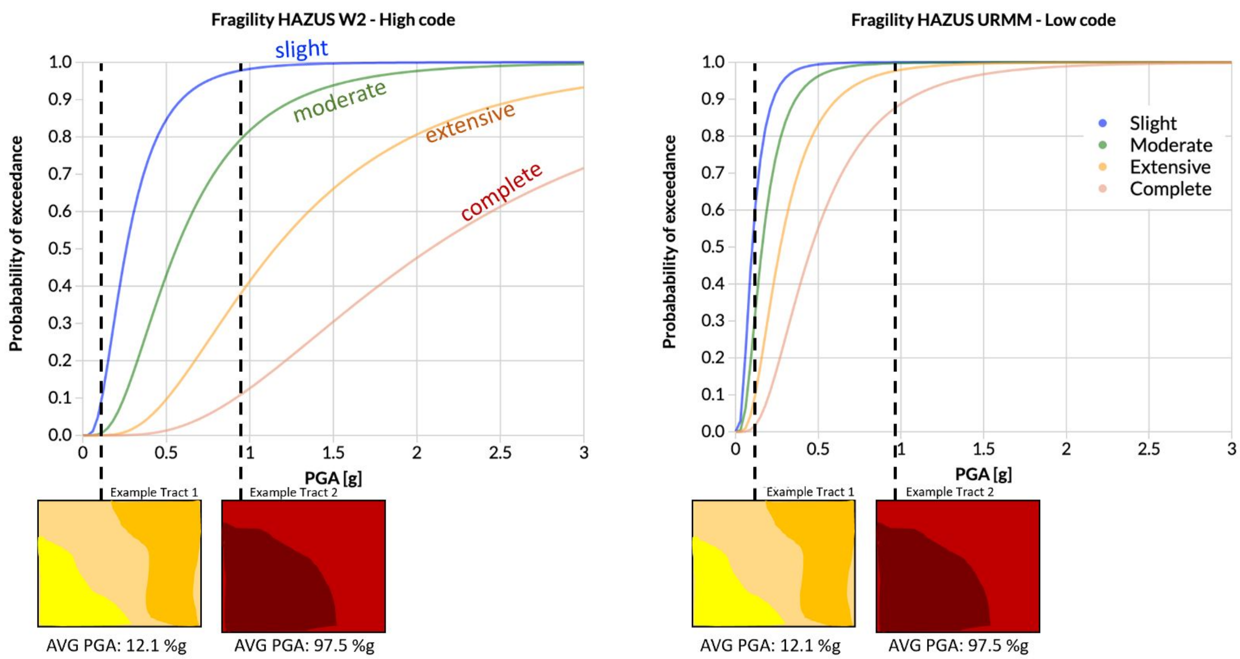
Earthquake Model Results vs. Hazus Model Results for the Napa 2014 M 6.0 Earthquake (Red/Destroyed Buildings per Tract):





There are a few significant differentiators between this code and the Hazus model itself which results in slightly different model outputs (a difference of less than 10 buildings per tract in this test case):

- **Seismic Design Code**: This model assumes the highest possible seismic design code for structures, resulting in more conservative damage estimates. The Hazus program customizes the seismic design code based on the seismic hazard of the impacted region as well as the year the structures were built.
- **Tract-level hazard**: Peak Ground Acceleration (PGA) determines the probability of meeting or exceeding each damage state and in order to do this analysis at the Tract-level, a single PGA must be generalized for an entire tract, which, depending on the size of the tract, is likely not the case. The Python model assigns the *minimum* PGA to each tract, resulting in more conservative damage estimates.



- **General Building Stock**: This model uses the count of building centroids within each Tract for structure count, whereas Hazus uses an estimation of structure counts based on Census demographics.

Future iterations of this work will include:

- Converting program to entirely open source (removing arcpy dependencies)
- Enabling analysis at the structural level using parcel data attribution spatially joined to building centroids and mapping those attributes to the Hazus structure types.
- Ability for user to define the Seismic Design Code as a parameter for Tract-level analysis, or calculation of Seismic Design Code based on Seismic Hazard and Year Built for the Structural-level analysis.