GEM's Vulnerability Modeller's Toolkit (VMTK)

The webinar will begin shortly…

BASIC USERS SESSION

10:00 - 10:30

Helen Crowley, Eucentre

Introduction to GEM's VMTK
- Scope of the VMTK
- Main features of the VMTK (GUI version)
- Installation on Mac and Windows

10:30 - 11:00

Martina Caruso, GEM Foundation

Example application of VMTK

11:00-11:45

Q&A + short break (time permitting)

ADVANCED USERS SESSION

11:45 - 12:30

Luis Martins, GEM Foundation

Tour of the VMTK GitHub Repository+ Q&A

WRAP-UP

12:30 -13:00

Vitor Silva, GEM Foundation

GEM's plans for vulnerability modelling

Introduction to GEM's VMTK

EFEHR-GEM Joint Webinar

Helen Crowley, EUCENTRE

European Seimic Risk Services
http://risk.efehr.org

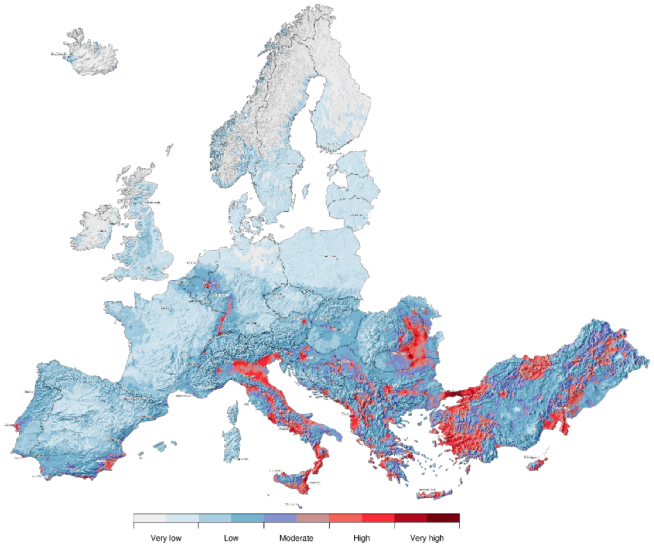
24/04/2023

EFEHR-GEM Joint Webinar on GEM's VMTK

- EFEHR: European Facilities for Earthquake Hazard and Risk www.efehr.org
  - Provides access to open data and models for seismic hazard and risk assessment at the European scale
  - Maintains ESHM20 http://hazard.efehr.org and ESRM20 http://risk.efehr.org
  - Organises working groups (e.g. Testing of hazard and risk models), scientific webinars and training events
- GEM: Global Earthquake Model www.globalquakemodel.org
  - non-profit, public-private partnership that drives a global collaborative effort to develop scientific and high-quality resources for transparent assessment of earthquake risk, and to facilitate their application for risk management around the globe.

Use of GEM's VMTK in ESRM20

- European Seismic Risk Model (ESRM20)
  - We ran the VMTK with capacity curves developed for 100's of European building classes together with European strong motion records (ESM) to produce vulnerability models for economic loss and fatalities.
  - The Python code (a modified version of the open source VMTK) and associated assumptions we used are all available here:



https://gitlab.seismo.ethz.ch/efehr/esrm20_vulnerability/-/tree/master/scripts/vmtk

Objectives of the Webinar

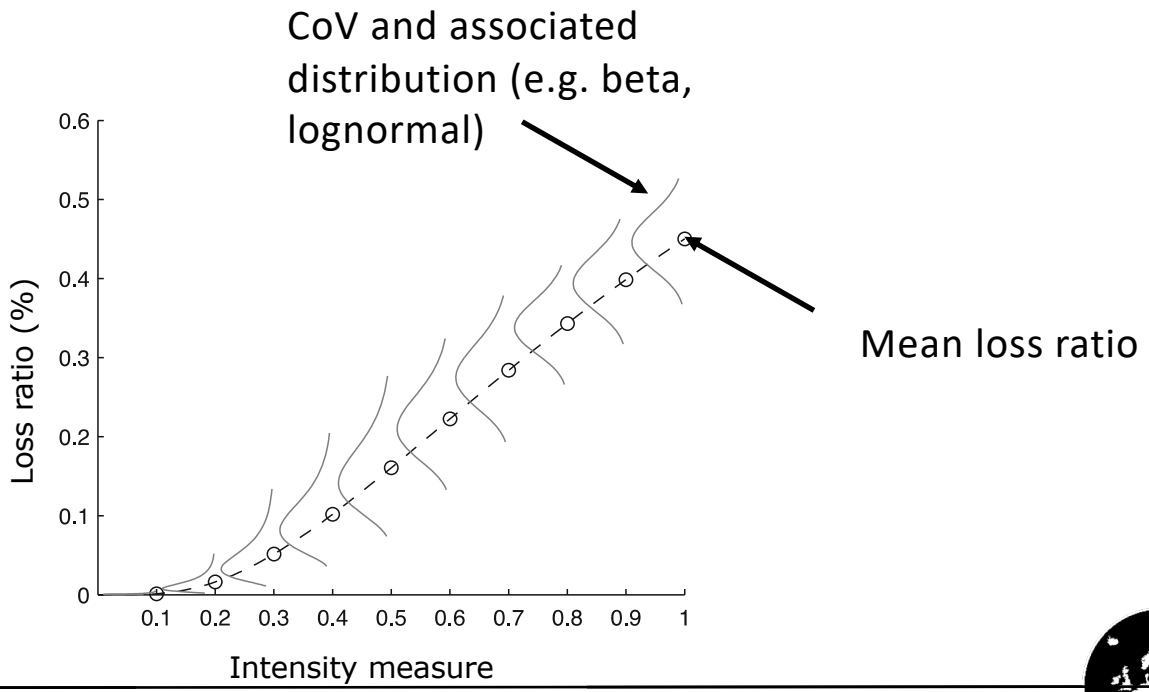
- Explain the rationale and workflow of the VMTK and the main scientific features
- Show an example application using the VMTK based on a user-defined capacity curve, damage thresholds and damage-loss model
- Give a brief tour of the GitHub repository where the open source code is hosted and explain some of the main scripts that can be modified
- Present a summary of future vulnerability modelling plans at GEM
- Answer your questions about the VMTK (please use the Q&A box)

Note that we will record the webinar so you can come back and watch it again, when you try out the VMTK for yourself!

Vulnerability Modelling

- What do we mean by vulnerability?

  Probability of loss (ratio), conditional on levels of intensity:



How can we produce vulnerability models?

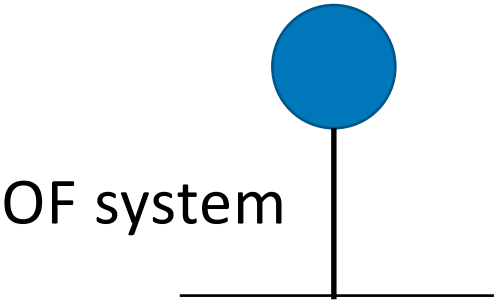
- Site specific (single building) versus regional (building class)?
- Analytical versus empirical?
- Few MDOFs or many SDOFs?
- Static versus dynamic?
- IDA/cloud/multiple-stripe?

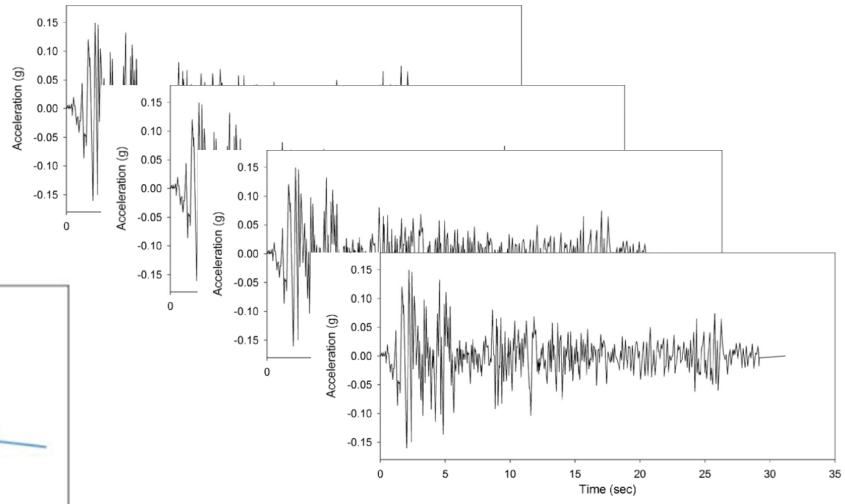
Default of VMTK

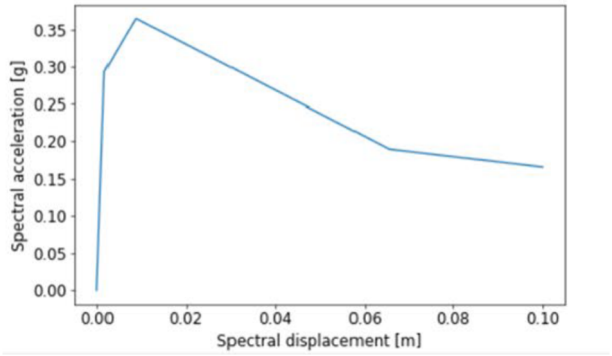
Note: The VMTK is open source code and can be easily modified to consider MDOF models with different hysteretic properties, and different nonlinear response methods – Luis Martin's presentation

VMTK – Main Concepts

SDOF system

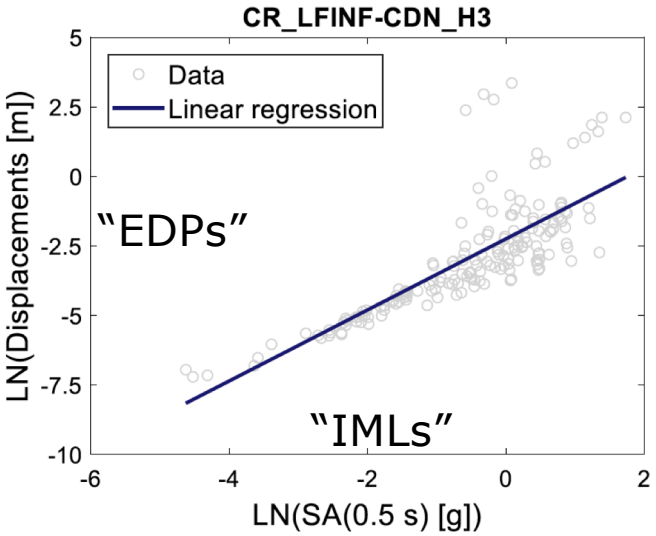






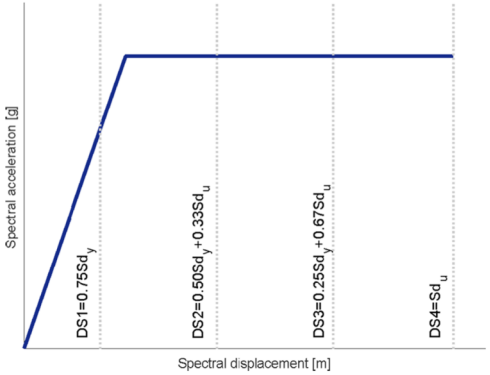
Capacity curve

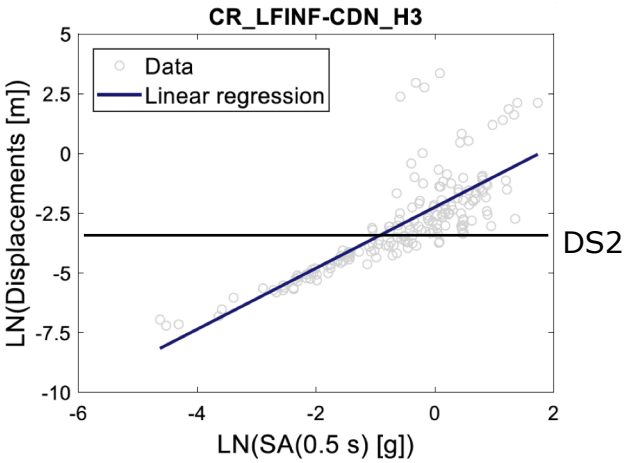
Nonlinear dynamic analyses



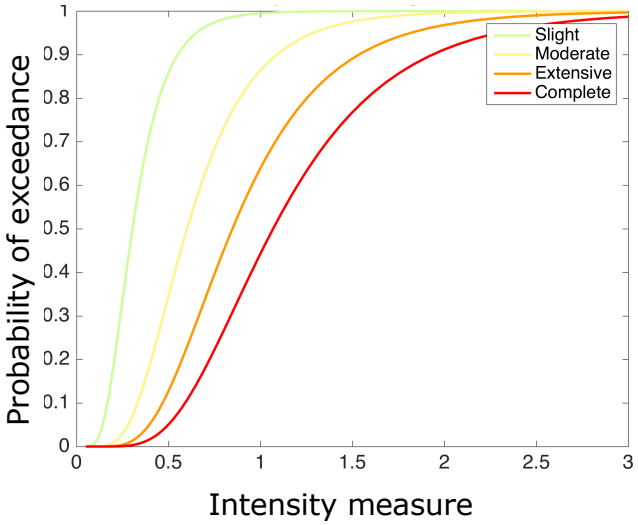
Cloud analysis, linear regression

VMTK – Main Concepts

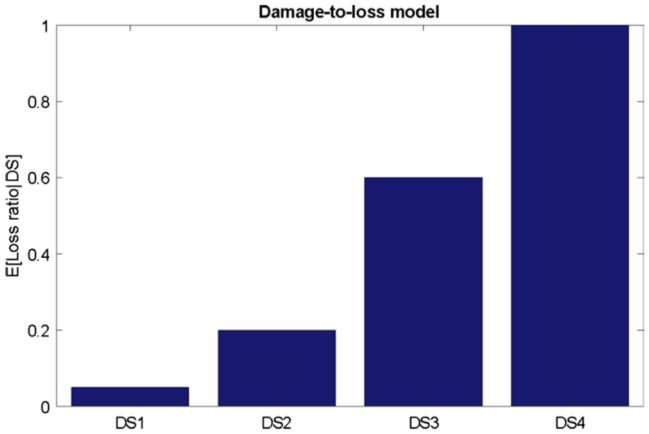




Damage thresholds



Probability of exceeding damage thresholds - Fragility functions



Conversion models (e.g. damage-loss model)

Steps of GEM's VMTK (Default/GUI version)

1. Demand module: selection of records
2. Capacity module: input of capacity curves
3. Structural response module: cloud analysis
4. Fragility module: application of damage thresholds
5. Vulnerability module: application of consequence models
6. Comparison: compare with other models
7. Verification: produce average annual risk metrics

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https://doi.org/10.1007/s10518-021-01187-w

ORIGINAL ARTICLE

Vulnerability modellers toolkit, an open-source platform for vulnerability analysis

Luís Martins[1] · Vitor Silva[1,2] · Helen Crowley[3] · Francesco Cavalieri[3]

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Abstract
Vulnerability functions describe the expected loss for a given ground shaking intensity level and are an essential component in probabilistic seismic risk assessment. This manuscript presents a novel open-source platform for the derivation of analytical fragility and vulnerability models, covering state-of-the-art methodologies, and addressing critical issues in vulnerability modelling such as uncertainty propagation, validation/verification of results and sufficiency/efficiency of intensity measure types. This framework is divided into seven modules designed to guide users through the different stages of analytical vulnerability modelling from the selection of ground motion records to the validation and verification of the models. The platform was implemented in the Python programming language and it is freely accessible through a public GitHub repository. A graphical user interface is included with the toolkit and is intended to be a general-purpose method for modellers to interact with the vulnerability modellers toolkit (VMTK). Experienced users are encouraged to use Python's scripting capabilities to explore all the features of the VMTK source code and to contribute to future releases of the toolkit.

Keywords Open-source · Vulnerability analysis · Earthquake engineering

1 Introduction

Fragility models define the probabilities of exceeding a number of damage states conditional on a ground shaking intensity measure, whilst vulnerability models establish the probability of loss ratio conditional on a ground shaking intensity measure (e.g. Yepes-Estrada et al. 2016). Such models, alongside the seismic hazard and exposure counterparts, are an essential component in probabilistic seismic risk analysis or in modelling earthquake scenarios. Considering that the majority of economic losses and casualties due to earthquakes are a consequence of poor performance of manmade structures, understanding

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[3] Eucentre Foundation, Pavia, Italy

1. Demand Module

GEM - Vulnerability Modellers ToolKit

Demand | Capacity | Structural Response | Fragility Analysis | Vulnerability Analysis | Compare Results | Verify Results

Location of ground motion records: /Users/helencrowley/Documents/5-GitHub/VMTK Browse

Intensity measure: PGA

Use all records

Select records based on range of IMs

Target intensity measure bins: Values separated by commas

Number of records per IML: 0

Min scaling factor: 0.0

Max scaling factor: 0.0

Select records based on conditional spectrum method

Target intensity measure levels: Values separated by commas

Number of records per IML: 0

Min scaling factor: 0.0

Max scaling factor: 0.0

Vs30 [m/s]: 0.0

Hazard disaggregation file: Please select a file Browse

Output/selected gmrs directory: /Users/helencrowley/Documents/5-GitHub/VMTK Browse

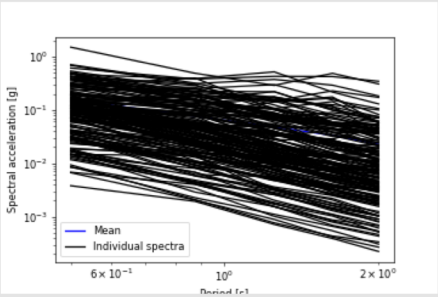
Start selection

Min T [s]: 0.5

Max T [s]: 2

No. steps T: 5

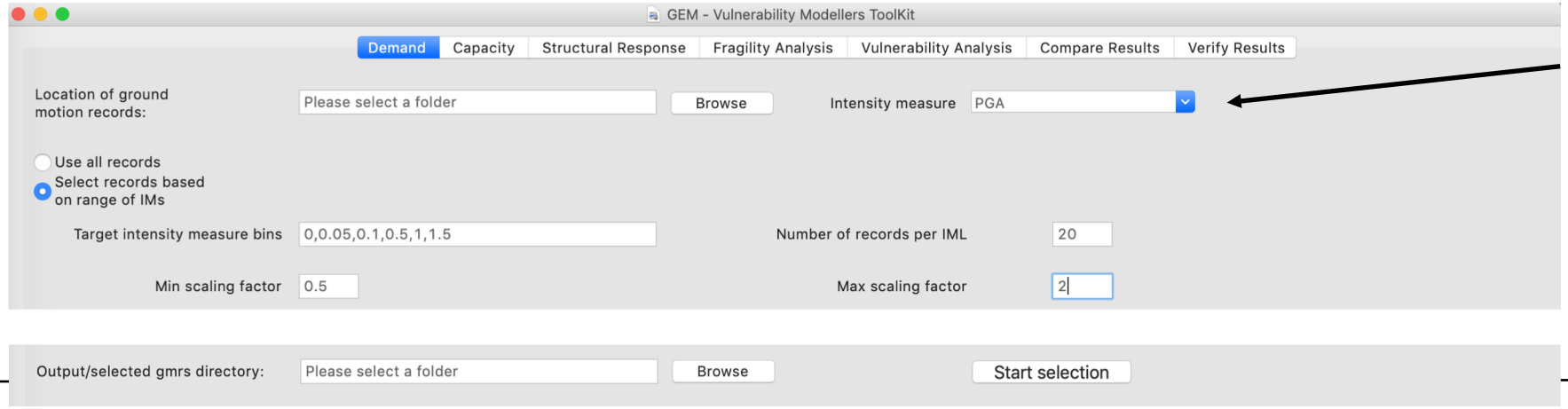
Plot spectra



1. Demand Module

User provides a database of records, then:

- Option 1: all records are used as they are
- Option 2: subset of records are selected based on intensity measure type, a list of intensity measure bins, number of records per level, min and maximum scaling factors:

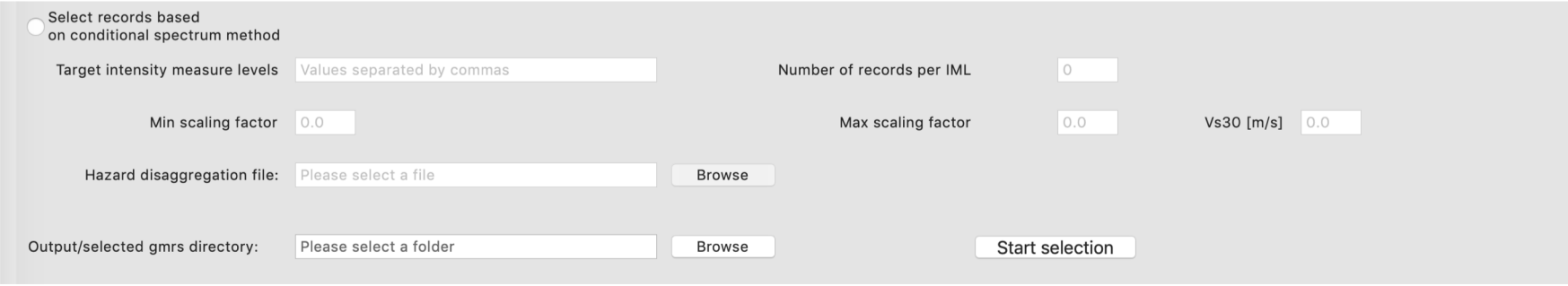


In the GUI there is a predefined list of IMs

1. Demand Module

User provides a database of records, then:

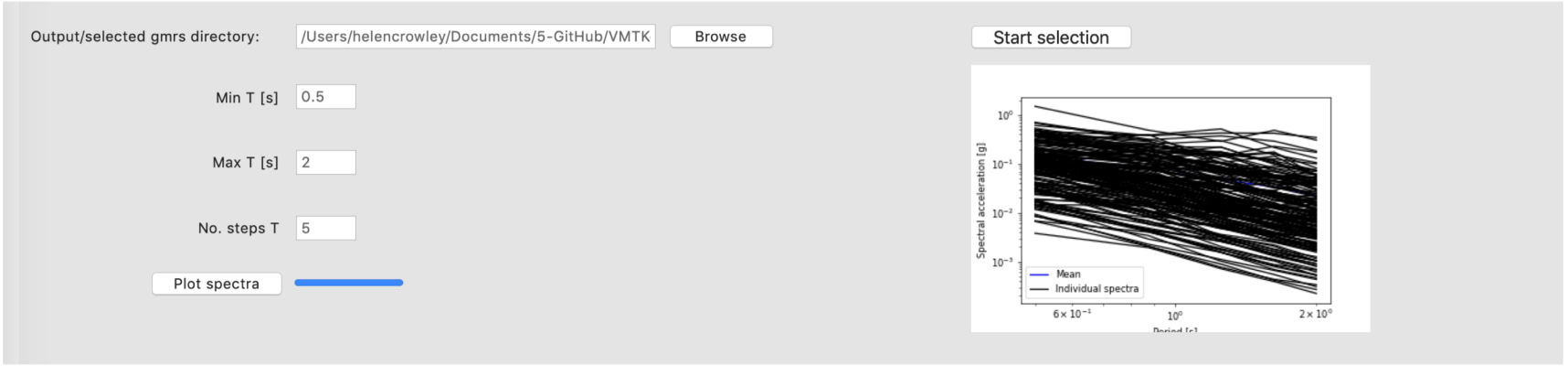
- Option 3: select records based on intensity measure type, the conditional spectrum method (using Baker and Lee (2018) algorithm), providing, in addition to previous inputs, a hazard disaggregation file (OpenQuake-engine format) and Vs30



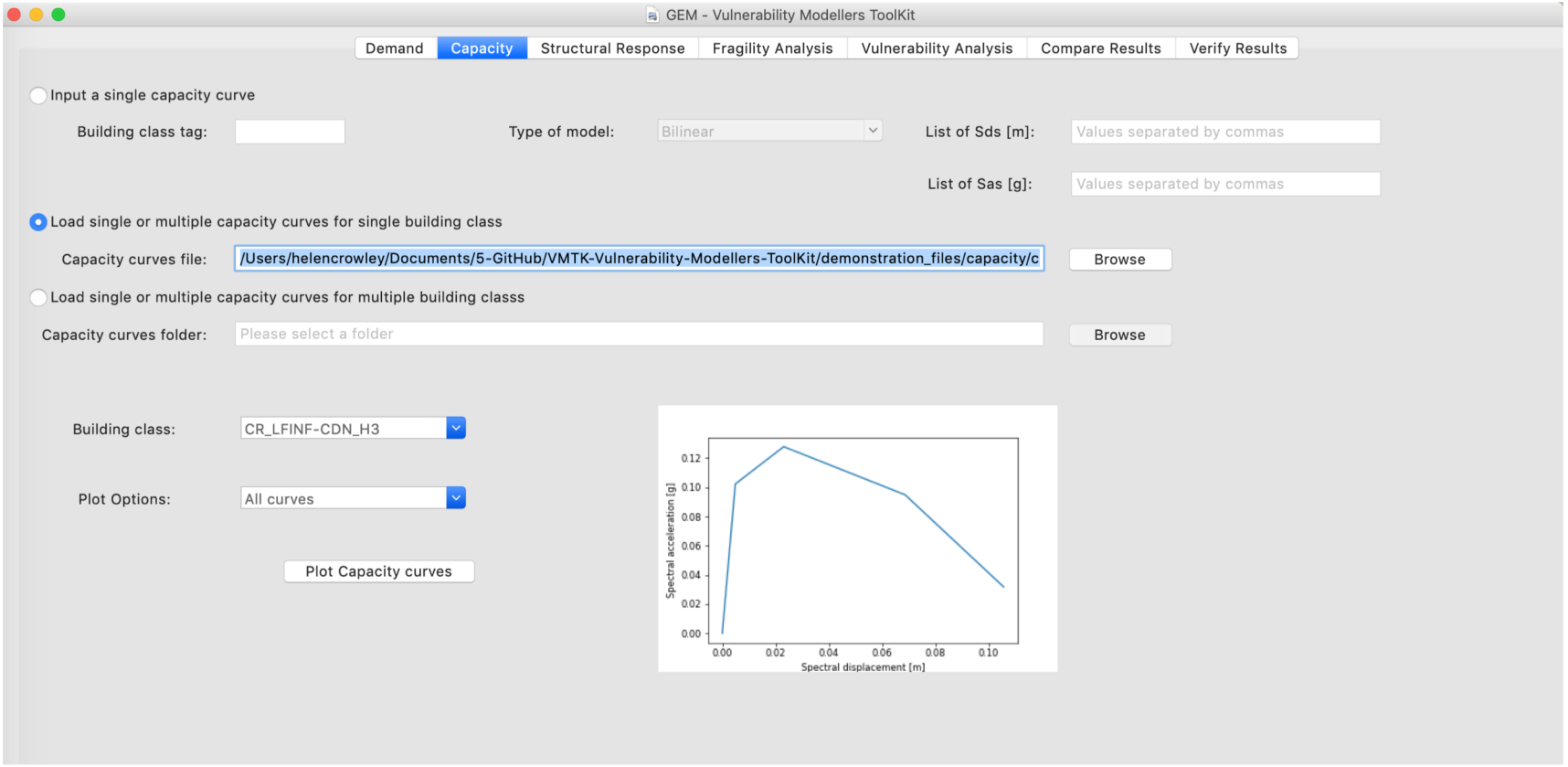
Baker and Lee (2018) DOI: https://doi.org/10.1080/13632469.2016.1264334

1. Demand Module

Users can then plot the spectra of the records, specifying minimum period (T, in secs), maximum period and number of steps:



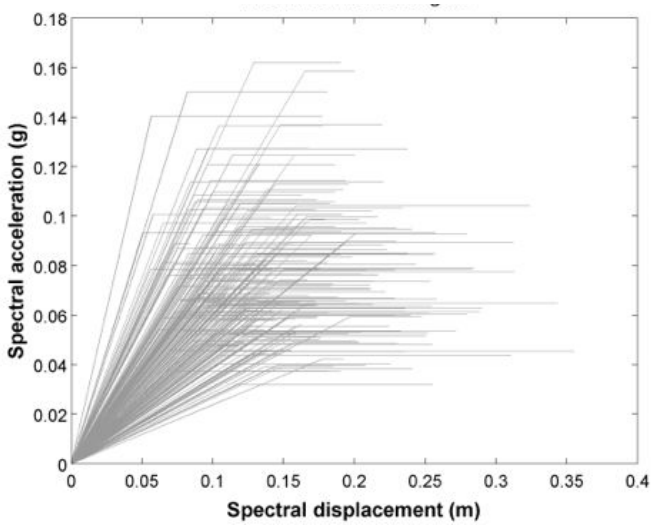
2. Capacity Module

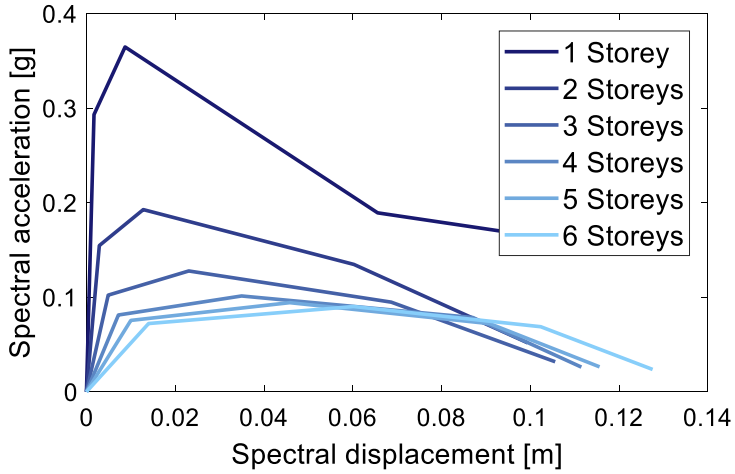


2. Capacity Module

Bilinear, trilinear or quadrilinear backbones (Sa vs Sd) are provided by the user

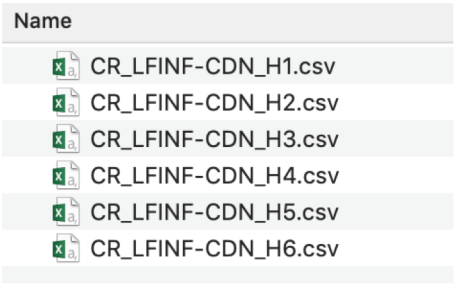
- Option 1: input a single capacity curve using the GUI
- Option 2: input single or multiple capacity curves for a single building class (.csv)
- Option 3: input single or multiple capacity curves for multiple building classes (.csv)





2. Capacity Module

- Format of uploaded capacity curves
  - A ‘csv’ file is uploaded for each building class
  - A single column of Sd (m) vs Sa (g) for single capacity curves:

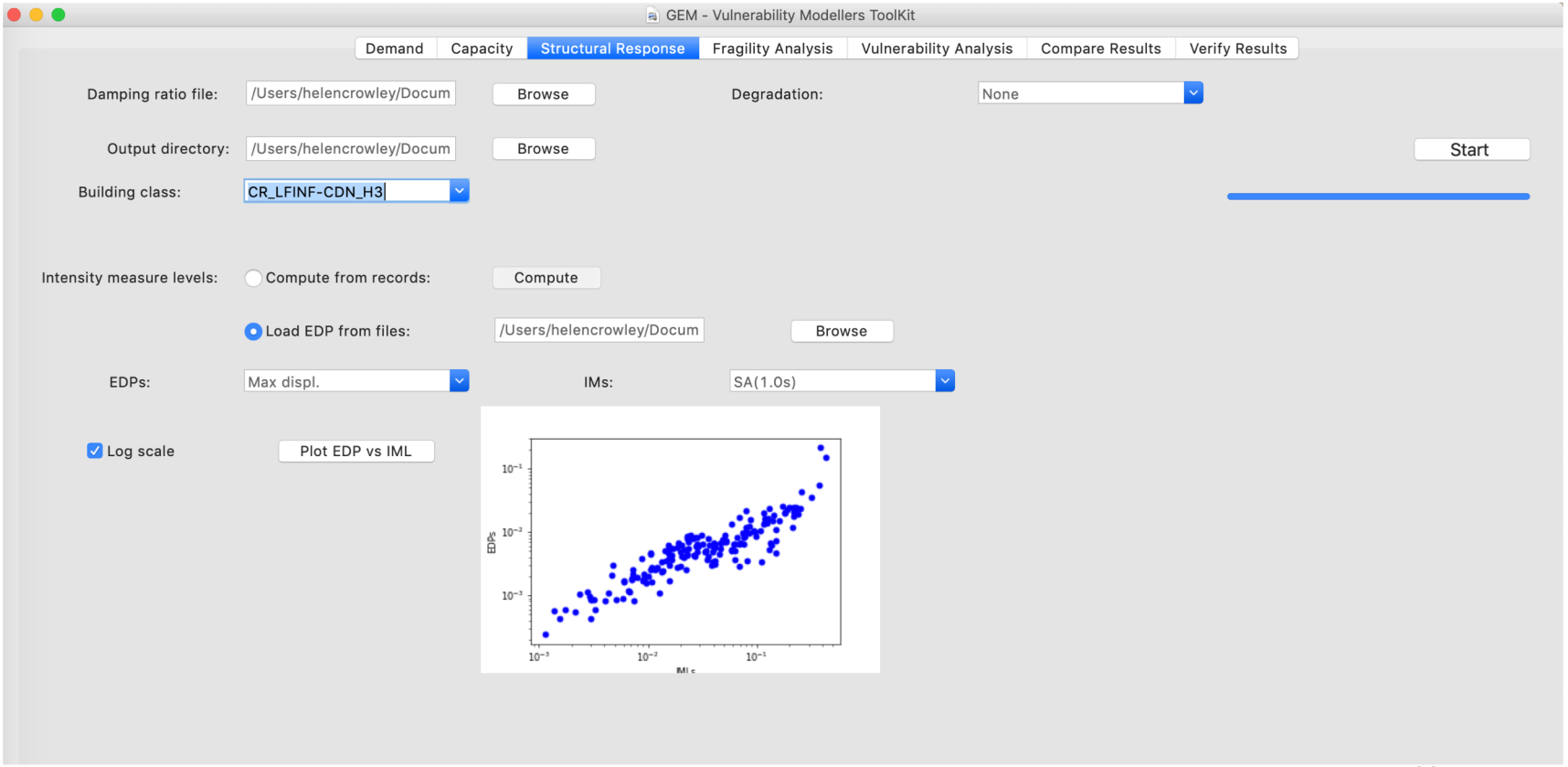


	A	B
1	0.0017	0.29314725
2	0.0087	0.36464592
3	0.0656	0.18924078
4	0.1	0.16531344
5		

  - Multiple columns of Sd (m) vs Sa (g) for multiple capacity curves:

	A	B	C	D	E	F
1	0.0017	0.29314725	0.0029	0.15465366	0.0049	0.10223172
2	0.0087	0.36464592	0.0128	0.19266946	0.02305	0.12778631
3	0.0656	0.18924078	0.06025	0.13470614	0.06865	0.09482145
4	0.1	0.16531344	0.0994	0.05178609	0.1056	0.03177373
5						

3. Structural Response Module



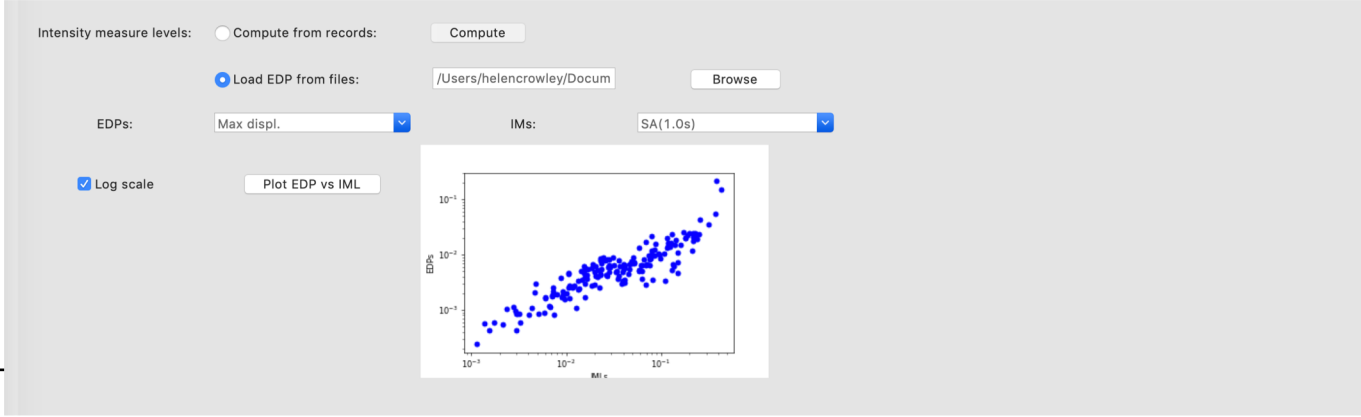
3. Structural Response Module

- OpenSeesPy is employed to compute the nonlinear response of each backbone curve to each record
- *Pinching4* is used as the default backbone curve, and the user can choose whether or not to include 'Energy' degradation.
- The damping ratio (mass proportional Rayleigh damping by default) is uploaded as a single .csv file with all building classes.

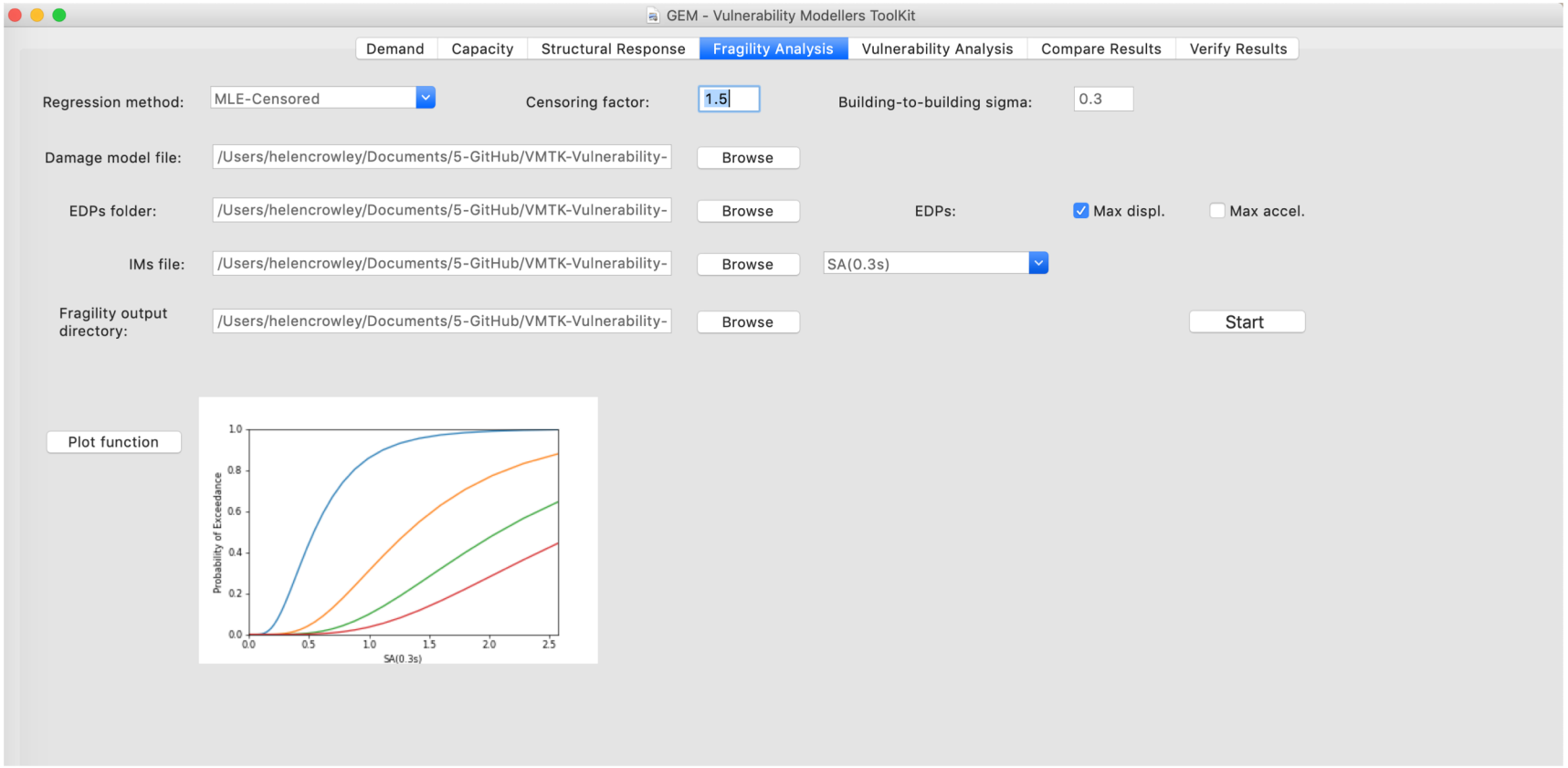
	A	B
1	CR_LFINF-CDN_H1	0.075
2	CR_LFINF-CDN_H2	0.075
3	CR_LFINF-CDN_H3	0.075
4	CR_LFINF-CDN_H4	0.075
5	CR_LFINF-CDN_H5	0.075
6	CR_LFINF-CDN_H6	0.075
7		

3. Structural Response Module

- After computing the nonlinear response (for a single class or all classes), the user can plot the results (one building class at a time) for “sanity checking”.
- If the user just wants to use the VMTK for regression analysis using response data computed elsewhere, they can also upload their own records at this point.

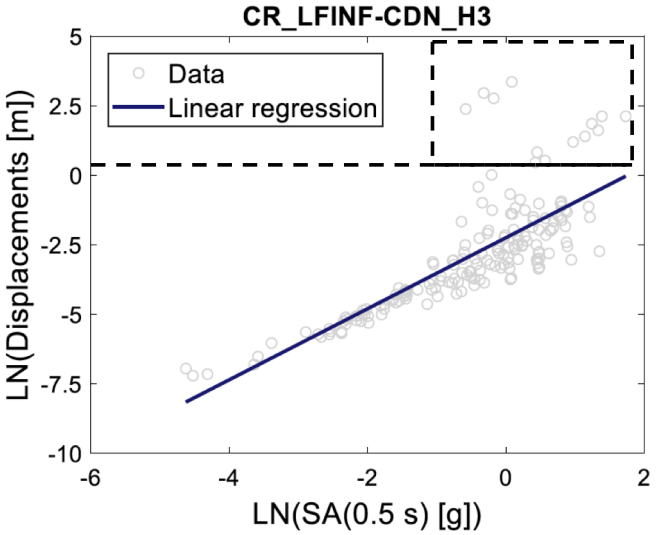


4. Fragility Module



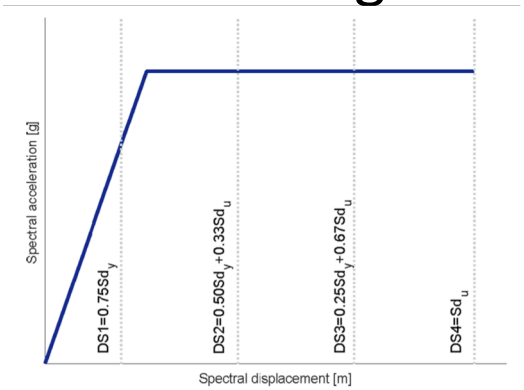
4. Fragility Module

- This module applies linear regression to the response (EDP) versus IML data.
- Uncensored regression considers all EDP data.
- Censored regression does not consider the value of responses that are beyond a limit (given by the ultimate threshold multiplied by a censoring factor) but does consider the fact that they have exceeded this threshold. Suggested scaling: 1.5



4. Fragility Module

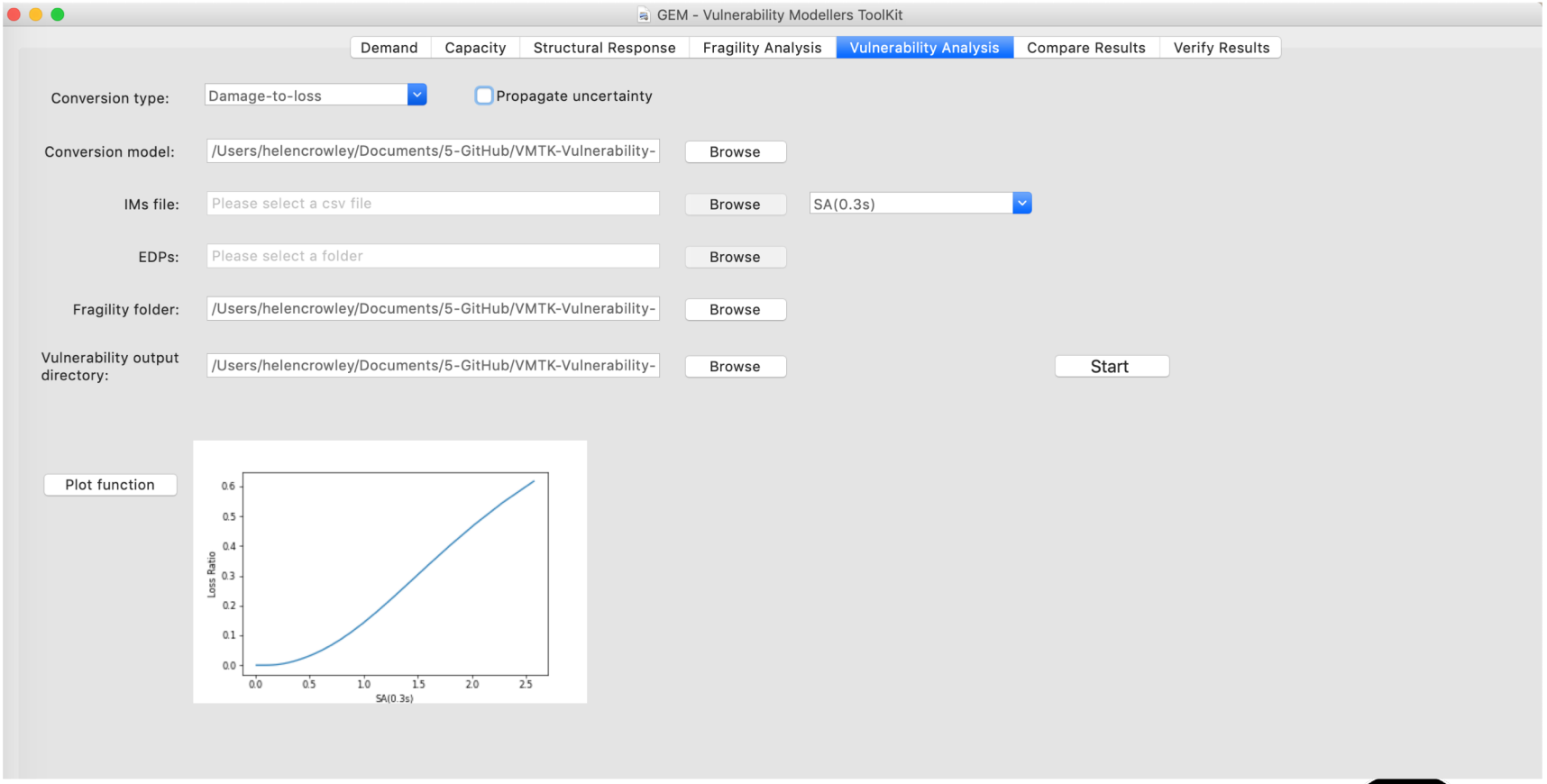
- Damage model files specifying the thresholds (displacement or acceleration) for each damage state are provided by the user.



	A
1	0.0172875
2	0.046373
3	0.0765145
4	0.1056
5	
6	

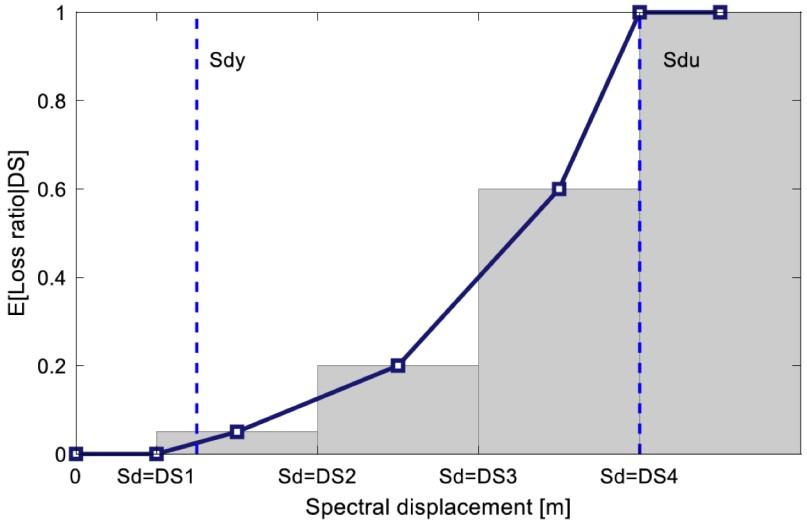
- The probability that the response exceeds each damage threshold, for varying intensity measure levels, is computed from the regression.
- If single capacity curves have been used, additional building-to-building variability can be input by the user. Suggested value: 0.3.

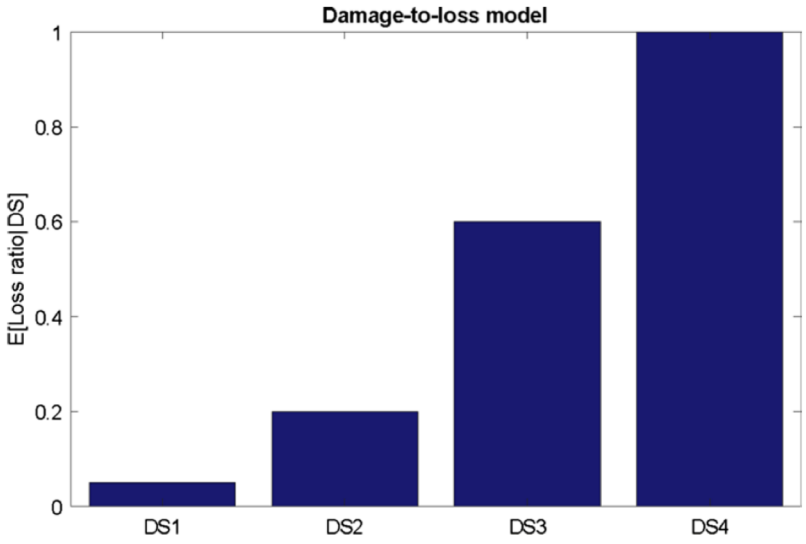
5. Vulnerability Module



5. Vulnerability Module

- There are two ways to compute vulnerability models
  - From the response (EDP) data, applying an EDP-to-loss model
  - From the fragility functions, applying a damage-to-loss model



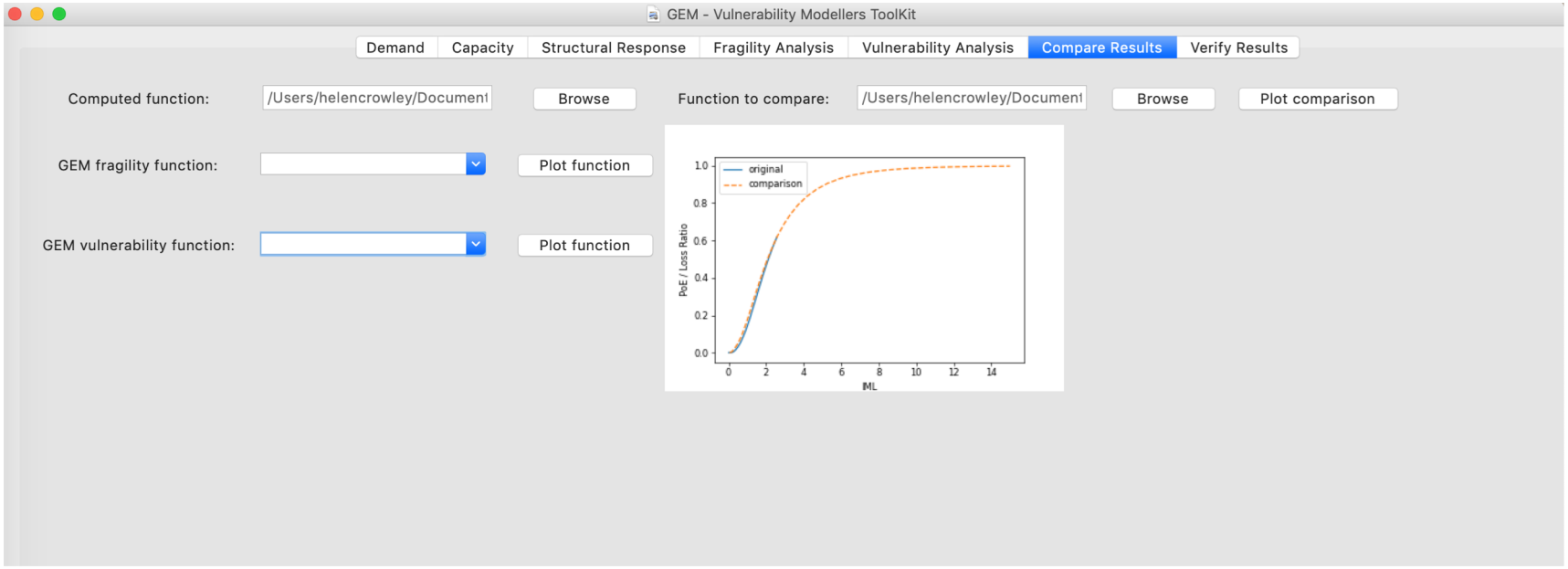


5. Vulnerability Module

- The user must upload the conversion model as a .csv file
- This file must have the same number of loss ratios as damage states.
- For damage-to-loss, only the mean loss ratios need to be provided, for EDP-to-loss, the EDP value and mean loss ratios should be input.
- 'Propagate uncertainty' computes the standard deviation of each loss ratio according to the formula from Silva (2019):

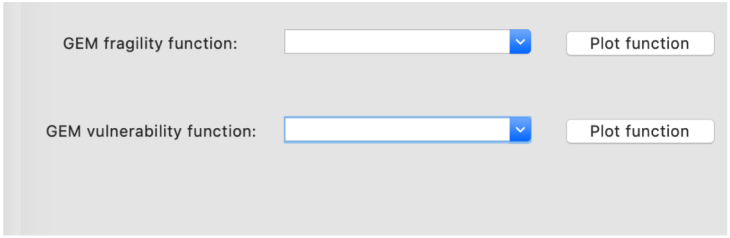
$$\sigma = \sqrt{MLR(-0.7 - 2 \cdot MLR + \sqrt{6.8 \cdot MLR + 0.5})}$$

6. Comparison

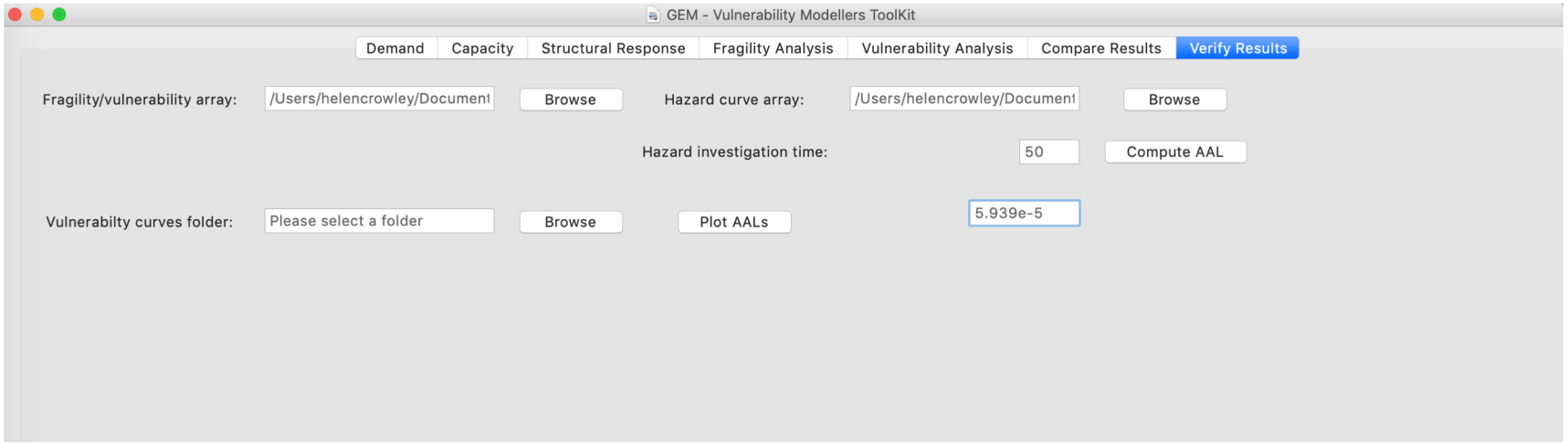


6. Comparison

- Users can upload, for one building class at a time, the computed fragility or vulnerability model and another model with which to make a comparison.
- In the VMTK, there is a folder called ‘validations’ which contains a set of GEM fragility and vulnerability models which can also be used for such comparisons.
- These models can also be plotted separately using the plotting feature at the bottom.

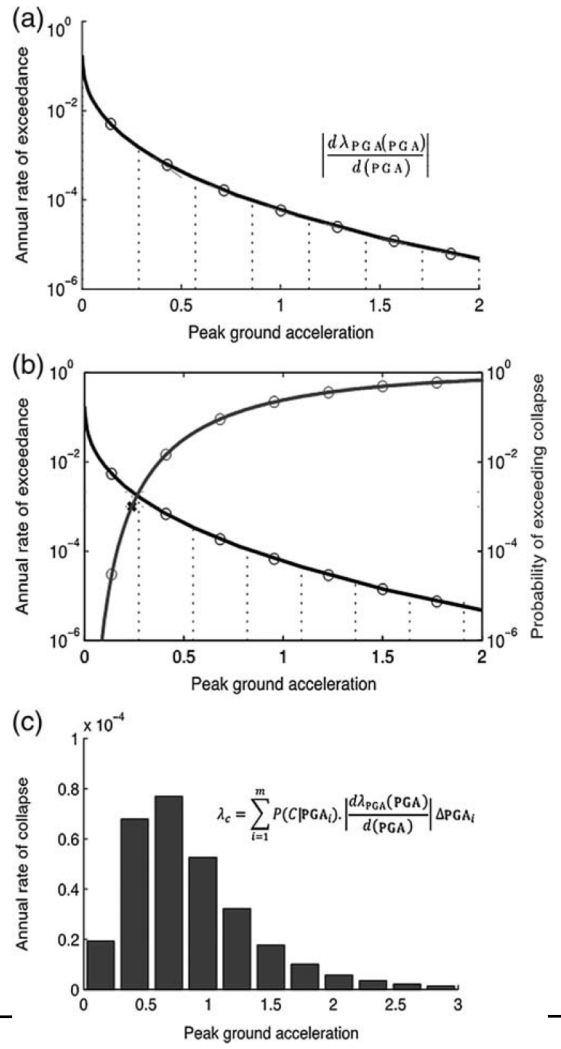


7. Verification



7. Verification

- As means to verify or sanity check the models, the user can compute the Average Annual Loss (AAL) for a building class at a specific location.
- If a fragility function is uploaded, the output is instead the Average Annual Probability of Near Collapse (or whatever the final damage state refers to).
- A hazard curve is uploaded (.csv of IML vs probability of exceedance). The user must specify the investigation time of the hazard curve.



7. Verification

- To compare the AAL of many building classes, the user can upload a folder with many vulnerability models and the tool with compute and plot them for comparison.

Installation on Mac and Windows

Requirements: Python3.8 or higher www.python.org

Note: to run Python on Windows you may need to edit environment variables, adding the path to the `python.exe` file and the `Scripts` folder, which are typically found in `AppData\Local\Programs\Python\Python38`

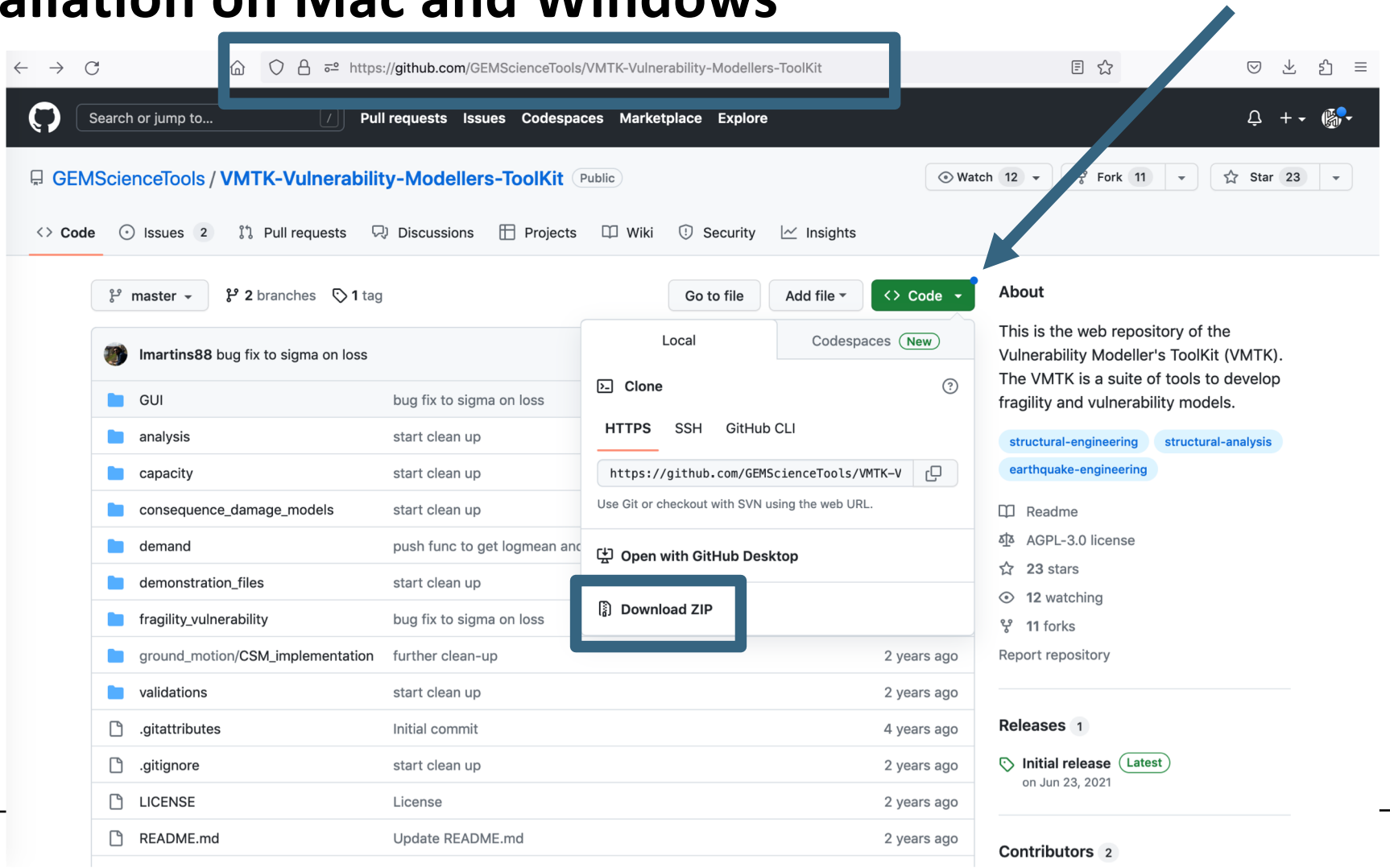
You also need to make sure you have the latest Microsoft Visual C++ runtime libraries (you can download these from: https://learn.microsoft.com/en-US/cpp/windows/latest-supported-vc-redist?view=msvc-170)

Note: You may alternatively install Anaconda https://docs.anaconda.com/ and create a virtual environment with Python3.8 within which to install the VMTK (we actually recommend this for both Mac and Windows!):

```
conda create -n VMTK python=3.8 anaconda

conda activate VMTK
```

Installation on Mac and Windows



Installation on Mac and Windows

Open up Terminal (on Mac) or Command Line Prompt (`cmd.exe` on Windows)

Navigate to the folder where you have installed the VMTK

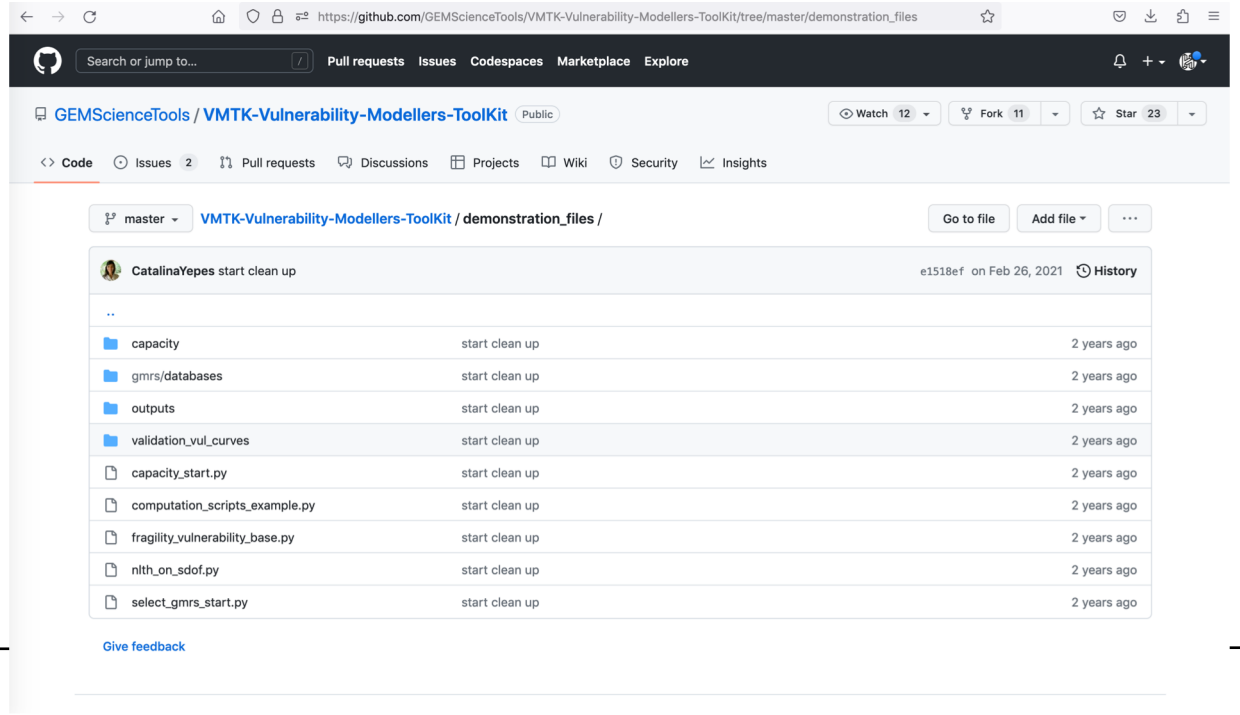
Type `pip install -r requirements.txt` and wait until installation is complete

Navigate to the GUI folder

Type `python Start_GUI.py` and the GUI will launch (might take a few seconds)

Getting Started

- A number of demonstration files are provided in the GitHub repository and can be used to check input formats and test out the various functionalities of the tool, before you use your own inputs.



Contact

Email the risk team @EFEHR: efehr.risk@sed.ethz.ch

Join GEM's OpenQuake Users Mailing list: https://groups.google.com/g/openquake-users

Acknowledgements

The development of the European hazard and risk models has been supported by funding from the European Union's Horizon 2020 research and innovation program under grant agreements No.s 730900, 676564 and 821115 of the projects SERA, EPOS-IP and RISE, and have been carried out in collaboration with GEM (Global Earthquake Model Foundation) and EPOS (European Plate Observing System).