

GEM's Vulnerability Modeller's Toolkit (VMTK)

The webinar will begin shortly...

BASIC USERS SESSION

10:00 - 10:30

Helen Crowley, Eucentre

- 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





EFEHR-GEM Joint Webinar on GEM's VMTK

- EFEHR: European Facilities for Earthquake Hazard and Risk <u>www.efehr.org</u>
 - 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 <u>www.globalquakemodel.org</u>
 - 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.



EFEH R

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





24/04/2023

Crowley et al. (2021) DOI: <u>https://doi.org/10.7414/EUC-EFEHR-TR002-ESRM20</u>



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

24/04/2023

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



Silva et al. (2019) DOI: https://doi.org/10.1193/042418EQS1010



VMTK – Main Concepts



EFEH R

VMTK – Main Concepts







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

ORIGINAL ARTICLE		
Vulnerability model	lers toolkit, an open-so	urce platform
for vulnerability and	lysis	
Luís Martins ¹ : Vítor Silv	a ^{1,2} · Helen Crowley ³ · Frances	sco Cavalieri ³
Received: 23 April 2021 / Accepte © The Author(s), under exclusive I	d: 15 July 2021 / Published online: 26 Ju icence to Springer Nature B.V. 2021	ly 2021
Abstract		
Vulnerability functions de	scribe the expected loss for a	given ground shaking intensity
level and are an essential of	omponent in probabilistic seisr	nic risk assessment. This manu-

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 ulmerability models, covering stard-of-heart 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 its freely accessible through a public GiHub repository. A graphical user interface is included 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, whits 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 estimic risk analysis or in modeling earthquake scenarios. Considering that the majority of economic losses and casualties due to earthquakes are consequence of poor performance of manmade structures, understanding

Global Earthquake Model Foundation, Pavia, Italy

² Faculty of Science and Technology, University Fernando Pessoa, Porto, Portugal

Eucentre Foundation, Pavia, Italy

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Luís Martins



	a	GEM - Vulnerability M	odellers ToolKit			
	Demand Capacity Structural Respon	nse Fragility Analy	vsis Vulnerability Anal	ysis 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	Num	ber 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	Numb	ber 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			10°		
Max T [s]	2		eleration [q]	10-1		
No. steps T	5		Spectral acc			
Plot spectra				10 ⁻³ Mean Individual spectra 6 × 10 ⁻¹ 10	2×10°	





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:

•			a GE	M - Vulnerab	ility Modell	ers ToolKit					
	Demand	Capacity	Structural Response	Fragility	Analysis	Vulnerability Ar	nalysis	Compare Results	Verify Results		In the GUI
Location of ground motion records: Use all records Select records based	Please select a fold	ler		Browse	In	tensity measure	PGA		•		there is a predefined list of IMs
Target intensity measure bins	0.0.05.0.1.0.5.1.1	.5			Number o	f records per IML		20			
Min scaling factor	0.5				N	lax scaling factor		2			
Output/selected gmrs directory:	Please select a fold	der		Browse			Start	selection			
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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

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:	Please select a folder	Browse		Start selection		
						<u>A</u>
Baker and Lee (2018) DOI: ht	tps://doi.org/10.1080/13	632469.	2016.1264334		Ę	24/04



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

Output/selected gmrs directory:	/Users/helencrowley/Documents/5-GitHub/VMTK	Browse	Start selection
Min T [s]	0.5		10°
Max T [s]	2		
No. steps T	5		
Plot spectra			10
			Daviad Tr1





2. Capacity Module

• • •	a GEM - Vulnerability Modellers ToolKit
	Demand Capacity Structural Response Fragility Analysis Vulnerability Analysis Compare Results Verify Results
Input a single capacity c	curve
Building class tag:	Type of model: Bilinear ✓ List of Sds [m]: Values separated by commas
	List of Sas [g]: Values separated by commas
• Load single or multiple c	capacity curves for single building class
Capacity curves file:	/Users/helencrowley/Documents/5-GitHub/VMTK-Vulnerability-Modellers-ToolKit/demonstration_files/capacity/c Browse
O Load single or multiple c	capacity curves for multiple building classs
Capacity curves folder:	Please select a folder Browse
Building class: Plot Options:	CR_LFINF-CDN_H3 All curves Plot Capacity curves



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:

	А	В
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:

	Α	В	С	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						

Name

CR_LFINF-CDN_H1.csv

CR_LFINF-CDN_H3.csv
 CR_LFINF-CDN_H4.csv
 CR_LFINF-CDN_H4.csv
 CR_LFINF-CDN_H5.csv

CR_LFINF-CDN_H6.csv





3. Structural Response Module

•••		a GEM	- Vulnerability Modell	ers ToolKit			
	Demand Ca	pacity Structural Response	Fragility Analysis	Vulnerability Analysis	Compare Results	Verify Results	
Damping ratio file:	/Users/helencrowley/Docum	Browse	Degradation:	None			
Output directory:	/Users/helencrowley/Docum	Browse					Start
Building class:	CR_LFINF-CDN_H3						
Intensity measure levels:	 Compute from records: Load EDP from files: 	Compute /Users/helencrowley/Docum	Brov	vse			
EDPs:	Max displ.	IMs:	SA(1.0s)	~			
C Log scale	Plot EDP vs IML	10-3 10-3 10-3 10-3 10-3 10-3 MI +	10-1				





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.

	А	В
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		



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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

•••			a GEM	M - Vulnerability Mo	odellers ToolKit			
		Demand Capacity	Structural Response	Fragility Analys	sis Vulnerability Analysis	Compare Results	Verify Results	
Regression method:	MLE-Censored	~	Censoring factor:	1.5	Building-to-building sigma:	0.3		
Damage model file:	/Users/helencrowle	ey/Documents/5-GitHub	/VMTK-Vulnerability-	Browse				
EDPs folder:	/Users/helencrowle	ey/Documents/5-GitHub	/VMTK-Vulnerability-	Browse	EDPs:	🗹 Max displ.	Max accel.	
IMs file:	/Users/helencrowle	ey/Documents/5-GitHub	/VMTK-Vulnerability-	Browse	SA(0.3s)	~		
Fragility output directory:	/Users/helencrowle	ey/Documents/5-GitHub	/VMTK-Vulnerability-	Browse			Start	
Plot function	buppatility of Exceedance 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.	10 15 20 SA(0.3s)	25					





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.



- 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-tobuilding variability can be input by the user. Suggested value: 0.3.





5. Vulnerability Module

• • •			a GEM	- Vulnerability M	lodellers ToolKit			
	Demand	Capacity	Structural Response	Fragility Analy	ysis Vulnerability Analysis	Compare Results	Verify Results	
Conversion type:	Damage-to-loss	Pro	ppagate uncertainty					
Conversion model:	/Users/helencrowley/Document	ts/5-GitHub/	VMTK-Vulnerability-	Browse				
IMs file:	Please select a csv file			Browse	SA(0.3s)	_		
EDPs:	Please select a folder			Browse				
Fragility folder:	/Users/helencrowley/Document	ts/5-GitHub/	VMTK-Vulnerability-	Browse				
Vulnerability output directory:	/Users/helencrowley/Document	ts/5-GitHub/	VMTK-Vulnerability-	Browse		Start		
Plot function	0.6 0.5 0.4 0.2 0.1 0.0 0.0 0.5 10 SA(0.35)	20	23					
								Cash



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

• • •		a GEN	1 - Vulnerability Modelle	ers ToolKit			
	Demand Capacity	Structural Response	Fragility Analysis	Vulnerability Analysis	Compare Results	Verify Results	
Computed function:	/Users/helencrowley/Document	Browse Fu	nction to compare:	/Users/helencrowley/Do	ocument Brows	e Plot comparison	
GEM fragility function:		Plot function	1.0 - original comparison				
GEM vulnerability function:		Plot function		8 10 12 14 ML			





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

•	• •		a GEM	I - Vulnerability Modell	ers ToolKit	
		Demand Capacity	/ Structural Response	Fragility Analysis	Vulnerability Analysis	Compare Results Verify Results
	Fragility/vulnerability array:	/Users/helencrowley/Document	Browse Haza	ard curve array:	/Users/helencrowley/Doc	Browse
			Hazard	investigation time:	£	Compute AAL
	Vulnerabilty curves folder:	Please select a folder	Browse	Plot AALs	5.939e-	-5



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.

•••		a GE	M - Vulnerability Modellers	ToolKit				
	Demand Capacity	Structural Response	Fragility Analysis	/ulnerability Analysis	Compare Results	Verify Results		
Fragility/vulnerability array:	/Users/helencrowley/Document	Browse	Hazard curve array:	/Users/helencrow	wley/Document	Browse		
			Hazard investigation tim	ie:	50	Compute AAL		
Vulnerabilty curves folder:	/Users/helencrowley/Document	Browse	Plot AALs]	4.825E-05			
0.007 0.006 0.005 0.003 0.003 0.002 0.001 0.000 − .cmF-CDN_H3_vulnerability_SAI0 − .cmF-C	DN_H2_vulnerability_SA(0 							
							CARL	24



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

С	ଲି ◯ 🔒 ᄙ http:	s:// github.com /GEMScienceTools	/VMTK-Vulnerability-Mo	odellers-ToolKit		E \$		ු එ ≡
Search or jump to	Pu	ll requests Issues Codespa	ces Marketplace E	xplore			¢ +	- B -
MScienceTools / V	/MTK-Vulnerabili ំា Pull requests ្	ty-Modellers-ToolKit	Public Wiki ① Sec	urity 🗠 Insights	⊙ Wa	tch 12 - 25 Fork 11	v the star 2	3 -
우 master -	🕈 2 branches 🛛 🕤 tag	3	Go to f	file Add file •	<> Code 👻	About		
Imartins88 bug fix to sigma on loss			Local	Codes	paces New	This is the web repository of the Vulnerability Modeller's ToolKit (VMTK). The VMTK is a suite of tools to develop		
GUI		bug fix to sigma on loss	HTTPS SSH GitHub CLI			fragility and vulnerabi	lity models.	
analysis		start clean up				structural-engineering	structural-analysis	
capacity		start clean up				earthquake-engineering		
consequence_	_damage_models	start clean up	Use Git or checkout wit	h SVN using the web L	IRL.	🛱 Readme		
emand		push func to get logmean and	다 Open with GitHu	ıb Desktop		좌 AGPL-3.0 license		
demonstration	n_files	start clean up				 ☑ 23 stars ☑ 12 watching 		
fragility_vulner	ability	bug fix to sigma on loss	Download ZIP			ੇ 12 watering % 11 forks		
ground_motion	n/CSM_implementation	further clean-up			2 years ago	Report repository		
validations		start clean up			2 years ago			
🗋 .gitattributes		Initial commit			4 years ago	Releases 1		
🗋 .gitignore		start clean up			2 years ago	♥ Initial release Late	st	
		License			2 years ago	on Jun 23, 2021		_
🗋 README.md		Update README.md			2 years ago	Contributors		
						Contributors 2		



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.

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S ⁹ master - VMTK-Vulnerability-Modellers-Te	oolKit / demonstration_files /	Go to file Add file - ····
CatalinaYepes start clean up		e1518ef on Feb 26, 2021 🕚 History
Capacity	start clean up	2 years ago
gmrs/databases	start clean up	2 years ago
outputs	start clean up	2 years ago
validation_vul_curves	start clean up	2 years ago
Capacity_start.py	start clean up	2 years ago
Computation_scripts_example.py	start clean up	2 years ago
fragility_vulnerability_base.py	start clean up	2 years ago
nlth_on_sdof.py	start clean up	2 years ago
select_gmrs_start.py	start clean up	2 years ago





Contact

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

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

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).

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