Scenario Damage Assessment Calculator Implementation

1. Description

This calculator is capable of computing the distribution of buildings in the various damage states (e.g.: no damage, moderate, collapse), given a single earthquake. This module requires the definition of a finite rupture, an exposure model and a fragility model. The main results are the damage distribution per asset, total damage distribution and collapse maps.
A blueprint for this calculator can be found at Launchpad through the following web link:
https://blueprints.launchpad.net/openquake/+spec/scenario-damage-assessment-calculator

2. Input

This calculator is very similar to the Scenario Risk calculator with regards to the input files however, instead of a vulnerability model, a fragility model is required.

2.1. Fragility model

Fragility functions describe the probability of exceeding a set of limit states, given an intensity measure level. Each limit state marks the threshold between the levels of damage that an asset might withstand. The number of limit states used in a fragility function can vary from 1 to any number, but usually not greater than 8. A fragility model can comprise several sets of fragility curves (one per building typology) and it should have a list of parameters common to the whole model, as follows:

- ID: unique key to identify the model;
- Description: a string in which a user can include a brief note about the model;
- Limit states: a list of the limit states considered in the model (e.g.: none to slight, moderate, extensive, collapse).
- Fragility functions format: an attribute to indicate which format was used to represent the fragility functions (continuous or discrete, as described in the following section).
- Taxonomy: Each set of fragility functions need to be classified according to a building taxonomy (string).

2.1.1. Discrete format

Fragility functions can be defined in a discrete way by providing, for each limit state, a list of intensity measure levels and respective probabilities of exceedance. Figure 1 presents a set of discrete fragility functions using a macroseismic intensity measure (MMI).

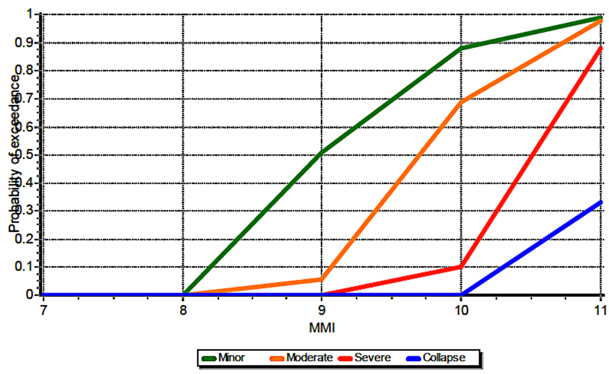

Figure 1 - Discrete Fragility Function.

These curves are simply a set of x values (intensity measure levels) and corresponding y values (probabilities of exceedance). The previously presented set of fragility functions was built using the values in Table 1.

Table 1 - Parameters of a discrete fragility function.

Limit states	VII	VIII	IX	X	XI
Minor	0.00	0.09	0.56	0.91	0.98
Moderate	0.00	0.00	0.04	0.78	0.96
Severe	0.00	0.00	0.00	0.29	0.88
Collapse	0.00	0.00	0.00	0.03	0.63

A fragility model can have many of the aforementioned set of fragility functions.

2.1.2. Continuous format

Continuous fragility functions are defined by the parameters of a cumulative distribution function (lognormal). In Figure 2 an example of a set of continuous fragility functions is presented.

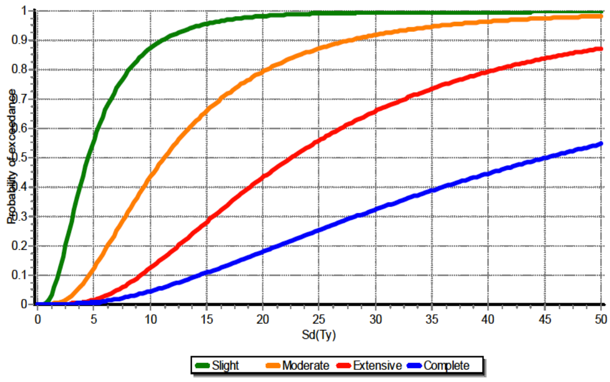

Figure 2 - Continuous fragility function.

In order to build each curve, it is necessary to know which cumulative distribution will be employed and the corresponding pair of parameters (usually a mean and a standard deviation or an alpha and beta values, depending on the type of cumulative function). Table 2 comprises the set of parameters that were used to build the set of fragility functions presented in Figure 2.

Table 2 - Parameters of a continuous fragility function.

Limit states	Mean	Standard deviation
Slight	11.19	8.27
Moderate	27.98	20.67
Extensive	48.05	42.49
Complete	108.9	123.7

A cumulative lognormal function was assumed to build the aforementioned functions. A fragility model can have many of the aforementioned set of fragility functions.

2.2. Exposure model

The exposure model used within this calculator follows the same format as the ones used in any of the already implemented calculators in OpenQuake. Nevertheless, it is important to understand that such calculations should be applied to large number of buildings usually assumed at single locations. Hence, the exposure model should be extended to incorporate information regarding the number and value of buildings in different fields. Currently this information is being stored in the same attribute (value), which means, only one of them can be stored. Creating a new attribute that would establish the **number of assets** would solve this issue, and the already existing attribute **value** would be used to indicate the value of a single asset.

2.3. Finite rupture

The earthquake rupture can be provided in the exact same format as the one used in the Scenario-based Loss Calculator.

2.4. Configuration file

In order to incorporate this calculator within OpenQuake, the configuration file needs to support a set of new parameters. The following list describes them:

- Flag to indicate that the Scenario Damage Assessment Calculator will be triggered.
- Flag to indicate if aggregated damage distributions should be computed.
- Flag to indicate if a collapse map should be extracted.

The remaining structure of the configuration file should follow exactly what has been established for the Scenario Risk Calculator.

3. Calculator

The initial workflow of this calculator is somehow very similar to the one from the Scenario Risk Calculator, as can be seen in the workflow in Figure 3.

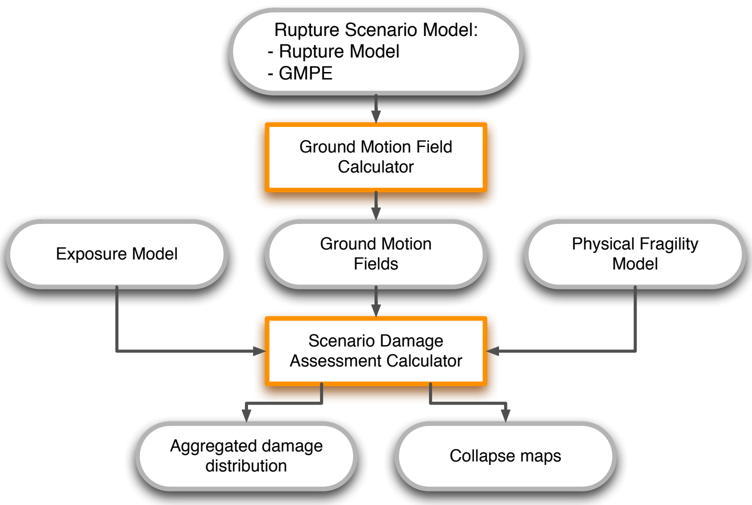

Figure 3 - Scenario damage assessment workflow.

The workflow of this calculator can be organized in 4 steps, as described below.

- **Step 1 – Ground motion fields**

A set of ground motion fields is required in order to represent the aleatory variability (both inter- and intra-event) in the ground motion prediction equation. This means, for each location, OpenQuake needs to produce a set of ground motion values.

- **Step 2 – Fraction of buildings per damage states**

The fraction of buildings in each damage state is equal to the distance between the associated limit state curves, with the exception for the first and last damage state. For the former, the fraction will be equal to 1 minus the probability of exceedance for the first limit state, whereas for the latter, the fraction will be equal to the probability of exceedance for the last limit state. This process is illustrated in Figure 4, where the fractions of buildings for a given intensity measure level, are extracted from a discrete fragility function.

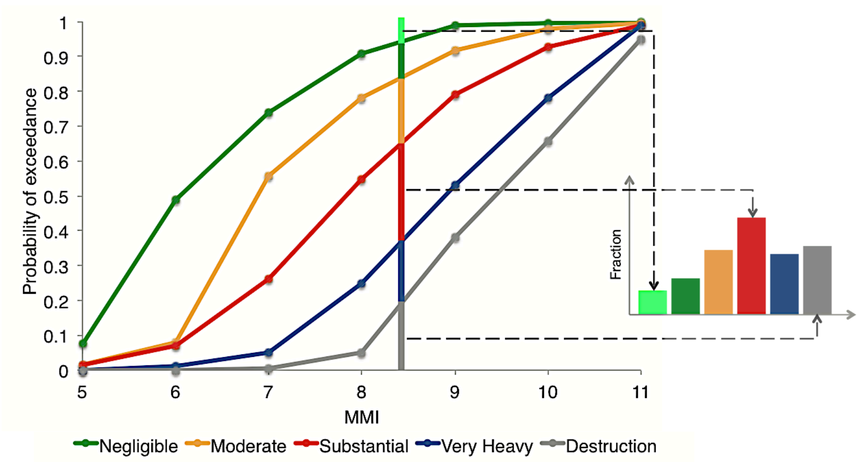

Figure 4 - Extracting fraction values from a discrete fragility function.

It is very likely that the intensity measure levels from the ground motion fields are not exactly the ones used in the fragility model. In those cases, linear interpolation should be employed. For instance, in the situation presented in Figure 4, each fraction was estimated using the probabilities of exceedance calculated through linear interpolation between MMI equal to 8 and 9. This issue does not happen when continuous fragility functions are used. In this case, each probability of exceedance can be computed for any intensity measure level by using the formula of the cumulative function, as follows:

$$PoE(IML) = CDF(IML, \mu, \sigma)$$

Where μ and σ stand for the mean and standard deviation of the cumulative function respectively. Often these functions do not have an analytical formula and therefore, it is recommended to make use of existing libraries such as ScyPy. Assuming a lognormal cumulative function, a logarithmic mean equal to -0.2 and a logarithmic standard deviation equal to 0.1, the probabilities of exceedance could be computed using the following expression:

```
PoE(0.2) = scypy.stats.lognorm.cdf(0.2, 0.1, scale=scipy.exp(-0.2))
```

- **Step 3 – Damage distribution**

Once Step 2 is completed, OpenQuake should have for each asset a set of fractions per damage state. These values can be used to compute a mean and a standard deviation for each damage state, which represents the main result of this calculator. Moreover, the mean fractions of the last damage state (usually defined as collapse, complete or destruction) can be used to create a spatial distribution of the portion of assets in its final damage state, also know as collapse maps.

- **Step 4 – Aggregating damage distributions**

A user might want to aggregate the results in terms of building typology, or extract the total damage distribution (considering all of the assets). In the first case, OpenQuake should for each ground motion field, sum the fractions of each damage state within the same building typology. This resulting set of fractions per damage state for each building typology (defined by the asset taxonomy) should be used to compute the set of means and the standard deviations. For the second case (total damage distribution), the same process is repeated but without distinguishing the statistics in terms of building typology. This process is further explained in the QA tests section.

4. Output

4.1. Damage distribution per asset

The main output of this calculator is the distribution of damage per asset. This information should be stored in database and NRML schema. The following parameters should be stored:

- ID: unique key to identify the damage distribution mesh;
- Logic tree branch: even knowing that OpenQuake does not support logic trees in the risk calculations currently, this field should still be created.
- Limit state description: A list with the designation of each damage state.

These three parameters also need to be included in the outputs described in 4.2 and 4.3. Then, a damage distribution node should represent each location. Each node can contain one or more assets, and for each asset two sets of values are provided: mean fraction and standard deviation for each damage state.

4.2. Damage distribution per building

For this type of output, an ID, Logic tree branch label and Limit state description need to be incorporated. An attribute stating that the damage distribution is in terms of building typologies should also be included. Then, for each building typology, two sets of values are provided: mean fraction and standard deviation for each damage state.

4.3. Total damage distribution

Besides the three parameters described in 4.1, an attribute should also be included stating that these results refer to the whole portfolio of assets. A single damage distribution should be stored with two sets of values: mean fraction and standard deviation for each damage state.

4.4. Collapse maps

A collapse map represents the spatial distribution of fraction of buildings in the last damage state. An ID and Logic tree branch label should be included in this output, as well as an attribute with the designation of the last damage state (e.g.: collapse, destruction). Then, for each site, the mean fraction of buildings in the last damage state should be provided. It is very likely that many assets may exist at the same location. In those cases, the weighted mean should be utilized, using the number of buildings at the assets location to weight the values.

5. QA Tests

5.1. Input data

For these quality assurance tests, two building typologies distributed throughout three locations were considered. Well-verified data to test the generation of ground motion fields using the Deterministic Event-based Calculator (hazard module) does not currently exist. Hence, these QA tests were designed based on a synthetic set of ground motion fields, whose values are presented in Table 3.

Table 3 - Synthetic ground motion fields.

GMF	Locations		
	A	B	C
1	0.4	0.35	0.2
2	0.3	0.35	0.15
3	0.45	0.25	0.15
4	0.35	0.2	0.25
5	0.4	0.3	0.2

Four assets with the following characteristics comprise the exposure model:

Table 4 - Description of the exposure model

Asset	Location	Building	Number of
1	A	RC	100
2	A	RM	40
3	B	RC	70
4	C	RM	70

In order to provide results to fully test this calculator, two fragility models (discrete and continuous) were used. For both models, two limit states were considered, as presented in Table 5 and Table 6.

Table 5 - Discrete fragility model.

Typology	Limit states	Intensity measure levels			
		0.1	0.3	0.5	0.7
RC	LS1	0.05	0.20	0.50	1.00
	LS2	0.00	0.05	0.20	0.50
RM	LS1	0.03	0.12	0.42	0.90
	LS2	0.02	0.07	0.25	0.60

For the continuous fragility model, it was assumed that the fragility curves follow a cumulative lognormal function.

Table 6 - Continuous fragility model.

Typology	Limit states	Mean	Stddev	Log. mean	Log stddev
RC	LS1	0.20	0.05	-1.640	0.246
	LS2	0.35	0.10	-1.090	0.280
RM	LS1	0.25	0.08	-1.435	0.312
	LS2	0.40	0.12	-0.959	0.294

Note that although the logarithmic mean and logarithmic standard deviation were provided in Table 6, the fragility model should provide only the mean and standard deviation, and OpenQuake should calculate the corresponding logarithmic values.

5.2. Results using the discrete fragility model

In this section, the final and some intermediate results are presented. Table 7 presents the fractions of buildings in each damage state per asset, per ground motion field.

Table 7 - Fractions of building in each damage state per asset and per ground motion field.

Asset	Damage state	Ground motion fields				
		1	2	3	4	5
1	DS1	0.650	0.800	0.575	0.725	0.650
	DS2	0.225	0.050	0.263	0.188	0.225
	DS3	0.125	0.150	0.163	0.088	0.125
2	DS1	0.730	0.880	0.655	0.805	0.730
	DS2	0.110	0.050	0.140	0.080	0.110
	DS3	0.160	0.070	0.205	0.115	0.160
3	DS1	0.725	0.725	0.838	0.875	0.800
	DS2	0.188	0.188	0.125	0.100	0.150
	DS3	0.088	0.088	0.038	0.025	0.050
4	DS1	0.925	0.948	0.948	0.903	0.925
	DS2	0.030	0.020	0.020	0.040	0.030
	DS3	0.045	0.033	0.033	0.058	0.045

Using these values, a mean and a standard deviation across all ground motion fields can be extracted per asset, as presented in Table 8.

Table 8 – Mean fraction and standard deviation per asset.

Asset	Damage state	Mean	Standard deviation
1	DS1	0.680	0.086
	DS2	0.190	0.083
	DS3	0.130	0.029
2	DS1	0.760	0.086
	DS2	0.098	0.034
	DS3	0.142	0.051
3	DS1	0.793	0.067
	DS2	0.150	0.039
	DS3	0.058	0.029
4	DS1	0.930	0.019
	DS2	0.028	0.008
	DS3	0.043	0.010

The amount of buildings in each damage state can be obtained by multiplying the mean fraction and standard deviation of each asset by the associated number of buildings, as presented in Table 9.

Table 9 – Mean number of buildings and standard deviation per asset.

Asset	Damage state	Mean	Standard deviation
1	DS1	68.0	8.6
	DS2	19.0	8.3
	DS3	13.0	2.9
2	DS1	30.4	3.4
	DS2	3.9	1.4
	DS3	5.7	2.1
3	DS1	55.5	4.7
	DS2	10.5	2.7
	DS3	4.0	2.0
4	DS1	65.1	1.3
	DS2	2.0	0.6
	DS3	3.0	0.7

5.3. Results using the continuous fragility model

As mentioned before, it might be necessary to convert the parameters that define the cumulative function, as was demonstrated in Table 6. This intermediate step depends on the type of function assumed and specifications of the library. For normal and exponential functions no transformations are required, unlike what happens with lognormal and beta cumulative functions.

Using this continuous fragility model, the fractions of buildings in each damage state per asset, per ground motion field were computed. The results are presented in Table 10.

Table 10 - Fractions of building in each damage state per asset and per ground motion field.

Asset	Damage state	Ground motion fields				
		1	2	3	4	5
Asset 1	DS1	0.002	0.038	0.000	0.008	0.002
	DS2	0.267	0.621	0.150	0.436	0.267
	DS3	0.731	0.341	0.850	0.556	0.731
Asset 2	DS1	0.048	0.230	0.021	0.109	0.048
	DS2	0.393	0.568	0.271	0.512	0.393
	DS3	0.558	0.202	0.708	0.379	0.558
Asset 3	DS1	0.008	0.008	0.152	0.451	0.038
	DS2	0.436	0.436	0.704	0.517	0.621
	DS3	0.556	0.556	0.144	0.032	0.341
Asset 4	DS1	0.712	0.931	0.931	0.438	0.712
	DS2	0.275	0.069	0.069	0.489	0.275
	DS3	0.013	0.001	0.001	0.073	0.013

Using these values, a mean and a standard deviation across all ground motion fields can be extracted per asset, as presented in Table 11.

Table 11 – Mean fraction and standard deviation per asset.

Asset	Damage state	Mean	Standard deviation
1	DS1	0.010	0.016
	DS2	0.348	0.183
	DS3	0.642	0.198
2	DS1	0.091	0.084
	DS2	0.428	0.116
	DS3	0.481	0.195
3	DS1	0.132	0.188
	DS2	0.543	0.118
	DS3	0.326	0.237
4	DS1	0.745	0.203
	DS2	0.235	0.175
	DS3	0.020	0.030

The amount of buildings in each damage state can be obtained by multiplying the mean fraction and standard deviation of each asset by the associated number of buildings, as presented in Table 12.

Table 12 – Mean number of buildings and standard deviation per asset.

Asset	Damage state	Mean	Standard deviation
1	DS1	1.0	1.6
	DS2	34.8	18.3
	DS3	64.2	19.8
2	DS1	3.6	3.4
	DS2	17.1	4.6
	DS3	19.2	7.8
3	DS1	9.2	13.2
	DS2	38.0	8.2
	DS3	22.8	16.6
4	DS1	52.1	14.2
	DS2	16.5	12.3
	DS3	1.4	2.1

The results obtained using the continuous fragility model were used to calculate the remaining outputs.

5.4. Damage distribution by building typology

To compute the mean fraction and standard deviation for each damage state within a building typology, it is necessary to firstly compute the number/area of buildings in each damage state per asset and per ground motion field. Then, the number/area of buildings within the same typology and damage state is summed per ground motion field. If m ground motion fields were used, then a number equal to m of summed values should be obtained per damage state. Finally, a mean and a standard deviation across all ground motion fields can be computed. By dividing these results by the total number/area of buildings within the considered building typology, the fractions of each damage state are obtained. Table 13 presents the results for the case considered herein:

Table 13 - Aggregated damage distribution per building typology.

Typology	Damage state	Mean	Standard deviation
RC	DS1	10.2	12.9
	DS2	72.8	13.8
	DS3	87.0	21.5
RM	DS1	55.8	15.1
	DS2	33.6	14.2
	DS3	20.7	7.6

5.5. Total damage distribution

The total damage distribution requires a similar approach from the one previously presented in 5.4, but summing all the buildings within the same damage state per ground motion field and not only the ones within the same building typology. The results for this output are presented in

Table 14 - Total damage distribution.

Damage state	Mean	Standard deviation
DS1	66.0	12.1
DS2	106.4	21.7
DS3	107.6	26.2

5.6. Collapse map

A collapse map represents the spatial distribution of fraction of buildings in the last damage state. Frequently, many assets will exist at the same location. The result that should be provided is the weighted mean fraction, using the number/area of buildings to weight the values.

Table 15 - Collapse map.

Location	Mean collapse fraction
A	0.133
B	0.058
C	0.043