Classical PSHA-Based Damage Calculator

Introduction

The OpenQuake classical PSHA-based damage calculator convolves through numerical integration, the discrete or continuous damage state fragility functions for an asset with the seismic hazard curve at the location of the asset, to give the damage distribution for the asset within a specified time period.

Calculation Steps

1. If discrete fragility functions are being used for the damage analysis, OpenQuake can use linear interpolation to estimate the fragility values at a given number of intensity measure level points between the ones provided in the discrete fragility functions. The number of intermediate points can be specified in the job configuration file using the parameter **`steps_per_interval`**; the default number of intermediate points is zero (or equivalently, **`steps_per_interval = 1`**).

2. The hazard curves are computed using OpenQuake's hazard engine:
    - When using continuous fragility functions, the set of intensity measure levels at which the hazard is computed, $\{iml_j\}$, is determined using the two attributes **`minIML`** and **`maxIML`** defined in the fragility function definition, and the parameter **`continuous_fragility_discretization`** specified in the job configuration file:

      $$iml_j = minIML + j \times \frac{maxIML - minIML}{continuous\_fragility\_discretization}$$

      where $j = 0, 1, ..., continuous\_fragility\_discretization$

    - When using discrete fragility functions, the hazard values are computed at the intensity measure levels at which the discrete fragility values are defined. In this case, if the interpolation option in step 1 has been exercised (i.e., **`steps_per_interval`** has a value greater than 1), then the hazard values are computed at the intensity measure levels including the intermediate interpolated IML points.

3. The probabilities of exceedance of intensity measure levels given by the hazard curve (as computed in step 2), $Prob(IML \geq iml_j,\ t_H)$, are converted to *annual* frequencies of exceedance of intensity measure levels, $\lambda_{IML}(iml_j)$, assuming that ground motion occurrences follow a Poisson process:

$$\lambda_{IML}(iml_j) = \frac{-ln[1 - Prob(IML \geq iml_j,\ t_H)]}{t_H}$$

where t_H is the time period in years used in the hazard analysis,
and $\{iml_j\}$ is the set of intensity measure level points.

4. The annual frequency of occurrence of these intensity measure levels is computed by differentiation of the hazard curve:

$$\lambda'_{IML}(iml_j) \approx \frac{\lambda_{IML}\left(\frac{iml_{j-1}+iml_j}{2}\right)-\lambda_{IML}\left(\frac{iml_j+iml_{j+1}}{2}\right)}{\Delta iml_j}$$

$$\therefore \lambda'_{IML}(iml_j) \times \Delta iml_j \approx \lambda_{IML}\left(\frac{iml_{j-1}+iml_j}{2}\right) - \lambda_{IML}\left(\frac{iml_j+iml_{j+1}}{2}\right)$$

where $\Delta iml_j = \frac{iml_{j+1}-iml_{j-1}}{2}$.

5. The annual frequencies of exceedance for the set of damage states $\{d_i\}$ are computed as follows:

(5.i) First, the annual frequencies of occurrence of the set of intensity measure levels, as computed in step 4, are multiplied by the corresponding probabilities of exceedance of the damage states given these intensity measure levels. The probabilities of exceedance of the damage states are either obtained directly from the discrete fragility functions or calculated from the analytical expression of the lognormal cumulative distribution function for the continuous fragility functions.

(5.ii) Next, for each damage state, the products obtained in **(5.i)** are summed across all the intensity measure levels:

$$\lambda_{D \geq d_i} = \sum_j FR_i(iml_j) \times \lambda'_{IML}(iml_j) \times \Delta iml_j$$

where $\lambda_{D \geq d_i}$ is the annual frequency of exceedance for damage state d_i,
and $FR_i(iml_j)$ is the probability of exceedance of damage state d_i at an intensity measure level iml_j. For discrete fragility functions, $\left\{FR_i(iml_j)\right\}$ are simply the values of the fragility function for damage state d_i at intensity measure level iml_j. For continuous fragility functions, $FR_i(iml_j) = \Phi\left[\frac{ln(iml_j)-ln(\theta_i)}{\beta_i}\right]$, where $\Phi(.)$ represents the standard normal cumulative distribution function, θ_i is the median of the fragility function for damage state d_i, and β_i is the dispersion of the fragility function for damage state d_i. See note N5 for a more detailed explanation.

6. Assuming that exceedances of the damage states follow Poisson processes, the probabilities of exceedance for the set of damage states $\{d_i\}$ are related to the annual frequencies of exceedance calculated in step 5 and the exposure time period through:

$$Prob(D \geq d_i, t_R) = 1 - e^{-\lambda_{D \geq d_i} t_R}$$

where $Prob(D \geq d_i, t_R)$ is the probability of exceedance for damage state d_i in the time period t_R specified in the risk analysis configuration file.

7. The probability of occurrence for the set of damage states $\{d_i\}$ within the specified time period are computed from the probabilities of exceedance calculated in step 6 as follows:

$$Prob(D = d_i, t_R) = Prob(D \geq d_i, t_R) - Prob(D \geq d_{i+1}, t_R)$$
$$Prob(no\ damage, t_R) = 1 - \sum_i Prob(D = d_i, t_R)$$

Calculator Outputs

O1. The output of this calculator comprises point estimates of the probabilities of achieving certain damage states within a given time span for single assets, calculated asset by asset.

Notes

N1. This calculator assumes that there will be at most one event causing damage in the specified exposure time period.

N2. The time period used in the hazard analysis to obtain the hazard curve and the exposure time period used in the risk analysis may possibly be different, particularly when the hazard curves are externally supplied. The time period used in the hazard analysis is denoted as t_H ; the exposure time period used in the risk analysis is denoted as t_R .

N3. Epistemic uncertainty in the fragility functions is currently not considered in this calculator.

N4. In the case of continuous fragility functions, correlations between the logarithmic means and logarithmic standard deviations of the different damage states for an asset are currently not considered in this calculator.

N5. The continuous fragility functions are assumed to be well represented by the cumulative distribution function of the lognormal distribution. $ln(\theta_i)$ and β_i are the mean and standard deviation, respectively, of the normal distribution representing the $ln(IML)$ values for damage state d_i . Since IML is assumed to be lognormally distributed, the mean of $ln(IML)$ is equal to the median of IML .