



OPENQUAKE
calculate share explore

OPENQUAKE ENGINE **RISK QA REPORT**

Version 1.0.0

Testing procedures and quality assurance methods adopted in the development of the risk component of the OpenQuake Engine, an open source code for seismic hazard and physical risk calculation.



“OpenQuake: Calculate, share, explore”

Testing procedures
adopted in the
development of the risk
component of the
OpenQuake-engine

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Part I

Introduction

1. Software Testing

The current document describes the testing procedures adopted in the development of the hazard component of the OpenQuake-engine (OQ-engine), the open source hazard and risk software developed by the Global Earthquake Model initiative.

Nowadays seismic hazard analysis serves different needs coming from a variety of users and applications.

These may encompass engineering design, assessment of earthquake risk to portfolios of assets within the insurance and reinsurance sectors, engineering seismological research, and effective mitigation via public policy in the form of urban zoning and building design code formulation.

Decisions based on seismic risk results may have impacts on population, properties and capitals, possibly with important repercussions on our day-to-day life. For these reasons, it is recommendable that the generation of hazard models and their calculation is based on well-recognized, state-of-the-art and tested techniques, requirements that must be reconciled with the need to regularly incorporate recent advances given the progress carried out within the scientific community.

The features described below contribute to fulfill these requirements:

- Software should have a modular and flexible structure capable of incorporating new features and - as a consequence - offer users the most recent and advanced techniques. In very general terms, modularity is the level to which a component of a system can be moved, replaced or reused. In software design, modularity means the separation of the software into smaller independent components that can be implemented, maintained and tested easily and efficiently.
- Software should have and extensive test coverage which captures possible errors and avoids regressions (i.e. unexpected behaviors introduced by new features). Software testing (**myers2012**) is an important, complex and vast discipline which helps in developing methods and processes aimed at certifying the extent to which a computer code behaves according to the original design intent and user specifications.

The OQ-engine includes different levels of modularity. The first is the one separating the engine itself into a number of libraries (see Figure 1.1), each one containing well identified knowledge, objects and methods (e.g. the OQ-hazardlib includes objects and methods needed to compute probabilistic seismic hazard and the OQ-risklib contains methods to compute scenario

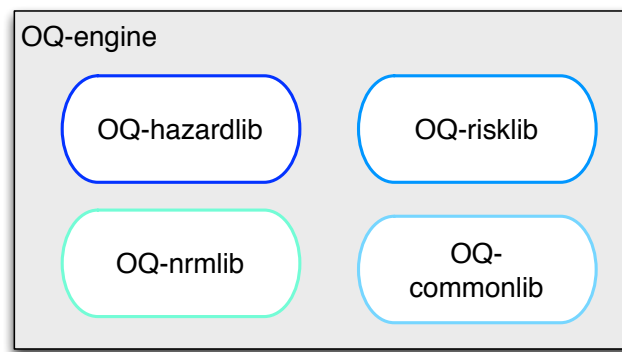


Figure 1.1 – A schematic describing the main components of the OpenQuake-engine software.

and probabilistic seismic risk).

The second one pertains to the data model adopted in the development of each library as a result of the abstraction process.

According to **berkes2012** scientific software must be:

- Error proof
- Flexible and able to accommodate different methods
- Reproducible and re-usable

1.1 Testing and Quality Assurance

Despite the distinction between software testing (in some cases also called Quality Control) and Software Quality Assurance (SQA) being somewhat vague and partly open to personal judgment, it's clear that SQA is a more comprehensive and overarching process than software testing. SQA aims at the definition of the best processes that should be used to provide guarantees that user expectations will be met. Software testing focuses instead on detecting software faults by inspecting and testing the product at different stages of development.

1.1.1 Software testing

Software testing can be implemented at different stages of the development process, with varying strategies to approach the problem. The OQ-engine and the associated libraries are developed following an agile paradigm. This development strategy is organized in a way that the creation of the real code is completed in parallel and fully integrated with the software testing process.

The software engineering community provides a wide range of testing levels and typologies. In the current document we consider just a portion of them with the specific intent to illustrate the standards used in the development of the OQ-engine and particularly of its risk calculation component.

1.1.2 Quality assurance

From the IEEE “Standard for Software Quality Assurance Processes”: *Software quality assurance is a set of activities that define and assess the adequacy of software processes to provide evidence that establishes confidence that the software processes are appropriate for and produce software products of suitable quality for their intended purposes. A key attribute of SQA is the objectivity of the SQA function with respect to the project. The SQA function may also be organizationally independent of the project; that is, free from technical, managerial, and financial pressures from*

the project. In this document we are not covering topics related to SQA since this would go beyond its scope.

1.2 Organization of Report

This document is organized into eight chapters.

The current chapter provides a very brief and general introduction to software testing with a focus on the testing of scientific software.

The second chapter describes the module, or unit testing procedures adopted in the development of the OQ-engine and we discuss some examples. The continuous integration mechanism used for development is also discussed.

The third chapter describes the general framework for the acceptance tests for the OpenQuake risk calculators. A brief overview of the theoretical background for the different calculators is also provided in this chapter.

The fourth chapter describes the different test cases, input models, and results for the acceptance tests implemented for the OpenQuake scenario risk, classical risk, and event-based risk calculators.

In the fifth chapter, we compare the loss curves computed using the event-based calculator with the corresponding loss curves computed using the classical-PSHA based calculator.

In the sixth chapter, we illustrate tests comparing the results computed with the OQ-engine against the ones computed using different probabilistic seismic risk analysis software.

Chapter seven describes the OpenQuake risk demos and the average

The final chapter describes the set of

Part II

Unit Tests

2. Unit Testing in the OpenQuake-engine

This chapter provides an introduction to the module (unit) testing procedures (**myers2012**) and describes the extensive series of tests implemented in the OQ-engine.

2.1 Overview of Unit-Testing

2.2 Continuous Integration

2.3 Unit-Tests in the OpenQuake Risk Library

2.4 Summary

Part III

Acceptance Tests

3. Framework for Acceptance Testing

3.1 Verification Framework

The main purpose of the acceptance tests is to ensure that the risk calculators work according to the design specifications and to verify that the calculators produce correct results for a variety of input cases. Correctness of the test case results is verified by comparing with hand calculations for the simple test cases or with alternate implementations in Julia for the complex cases.

3.2 Theoretical Background

3.2.1 Basic concepts

An earthquake *rupture model* describes the magnitude, geometry, and source typology of an earthquake occurrence.

Given an earthquake rupture, the simulation of ground shaking values on a set of locations $\mathbf{x} = (x_1, x_2, \dots, x_N)$ forms a *ground motion field (GMF)*. The ground motion field is simulated by sampling the probability distribution defined by the ground motion model.

Seismicity in a region is described by a seismic source model (*SSM*), which is a collection of *independent seismic sources*. Independence of seismic sources implies that the occurrence of an earthquake rupture in a source does not affect the probability of earthquake occurrence in the other sources.

The main parameters describing a seismic source are the geometry constraining the earthquake rupture locations, and the *magnitude-frequency distribution*, defining the average annual occurrence rate over a magnitude range. A seismic source model (*SSM*) can be therefore defined as a set of I seismic sources (*Src*):

$$SSM = \{Src_1, Src_2, \dots, Src_I\} \quad (3.1)$$

Each source generates *independent earthquake ruptures*. Independence of earthquake ruptures implies that the occurrence of an earthquake rupture in a source does not affect the probability of occurrence of the other potential earthquake ruptures in the same source. A generic i -th source defines therefore a set of J earthquake ruptures:

$$Src_i = \{Rup_{i1}, Rup_{i2}, \dots, Rup_{iJ}\} \quad (3.2)$$

Probabilistic seismic hazard analysis allows calculating the probabilities of exceeding, at least once in a given time span, and at a given site, a set of ground motion parameter levels considering all possible earthquake ruptures defined in a seismic source model. Such a list of probability values is usually referred to as *hazard curve*.

3.2.2 Scenario risk

The scenario risk calculator computes loss statistics for all assets in a given exposure model for a single specified earthquake rupture. Loss statistics include the mean and standard deviation of ground-up losses and insured losses for each loss type considered in the analysis. Loss statistics can currently be computed for five different loss types using this calculator: structural losses, nonstructural losses, contents losses, downtime losses, and occupant fatalities. This calculator requires the definition of a finite rupture model, an exposure model and a vulnerability model for each loss type considered; the main results are the loss statistics per asset and mean loss maps.

The rupture characteristics—i.e. the magnitude, hypocenter and fault geometry—are modelled as deterministic in the scenario calculators. Multiple realizations of different possible ground motion fields (GMFs) due to the single rupture are generated, taking into consideration both the inter-event variability of ground motions, and the intra-event residuals obtained from a spatial correlation model for ground motion residuals. The use of logic-trees allows for the consideration of uncertainty in the choice of a GMPE model for the given tectonic region and in the choice of vulnerability functions for the different taxonomy types in the exposure model.

As an alternative to computing the GMFs with OpenQuake, users can also provide their own sets of GMFs as input to the scenario risk calculator.

For each GMF realization, a loss ratio is sampled for every asset in the exposure model using the provided probabilistic vulnerability model, taking into consideration the correlation model for vulnerability of different assets of a given taxonomy. Finally loss statistics, i.e., the mean loss and standard deviation of loss for both ground-up losses and insured losses across all realizations, are calculated for each asset. Mean loss maps are also generated by this calculator, describing the mean ground-up losses and mean insured losses caused by the scenario event for the different assets in the exposure model.

3.2.3 Scenario damage

The scenario damage calculator computes damage distribution statistics for all assets in a given exposure model for a single specified earthquake rupture. Damage distribution statistics include the mean and standard deviation of damage fractions for different damage states. This calculator requires the definition of a finite rupture model, an exposure model and a fragility model; the main results are the damage distribution statistics per asset, aggregated damage distribution statistics per taxonomy, aggregated damage distribution statistics for the region, and collapse maps.

The rupture characteristics—i.e. the magnitude, hypocenter and fault geometry—are modelled as deterministic in the scenario calculators. Multiple realizations of different possible ground motion fields (GMFs) due to the single rupture are generated, taking into consideration both the inter-event variability of ground motions, and the intra-event residuals obtained from a spatial correlation model for ground motion residuals. The use of logic-trees allows for the consideration of uncertainty in the choice of a GMPE model for the given tectonic region and in the choice of fragility functions for the different taxonomy types in the exposure model.

As an alternative to computing the GMFs with OpenQuake, users can also provide their own sets of GMFs as input to the scenario damage calculator.

For each GMF realization, damage fractions (the fraction of buildings in each damage state) are estimated for every asset in the exposure model using the provided fragility model, and

finally the damage distribution statistics (i.e., the mean damage fractions and standard deviation of damage fractions for all damage states) across all realizations are calculated. The calculator also provides aggregated damage distribution statistics for the portfolio, such as mean damage fractions and standard deviation of damage fractions for each taxonomy in the exposure model, and the mean damage fractions and standard deviation of damage fractions for the entire region of study.

3.2.4 Classical PSHA-based risk

The classical PSHA-based risk calculator convolves through numerical integration, the probabilistic vulnerability functions for an asset with the seismic hazard curve at the location of the asset, to give the loss distribution for the asset within a specified time period. The calculator requires the definition of an exposure model, a vulnerability model for each loss type of interest with vulnerability functions for each taxonomy represented in the exposure model, and hazard curves calculated in the region of interest. Loss curves and loss maps can currently be calculated for five different loss types using this calculator: structural losses, nonstructural losses, contents losses, downtime losses, and occupant fatalities. The main results of this calculator are loss exceedance curves for each asset, which describe the probability of exceedance of different loss levels over the specified time period, and loss maps for the region, which describe the loss values that have a given probability of exceedance over the specified time period.

The hazard curves required for this calculator can be calculated by the OpenQuake engine for all asset locations in the exposure model using the classical PSHA approach (Cornell, 1968; McGuire, 1976). The use of logic-trees allows for the consideration of uncertainty in the choice of a GMPE model for the different tectonic region types in the region and in the choice of vulnerability functions for the different taxonomy types in the exposure model.

3.2.5 Classical PSHA-based damage

The classical PSHA-based risk calculator convolves through numerical integration, the probabilistic vulnerability functions for an asset with the seismic hazard curve at the location of the asset, to give the loss distribution for the asset within a specified time period. The calculator requires the definition of an exposure model, a vulnerability model for each loss type of interest with vulnerability functions for each taxonomy represented in the exposure model, and hazard curves calculated in the region of interest. Loss curves and loss maps can currently be calculated for five different loss types using this calculator: structural losses, nonstructural losses, contents losses, downtime losses, and occupant fatalities. The main results of this calculator are loss exceedance curves for each asset, which describe the probability of exceedance of different loss levels over the specified time period, and loss maps for the region, which describe the loss values that have a given probability of exceedance over the specified time period.

The hazard curves required for this calculator can be calculated by the OpenQuake engine for all asset locations in the exposure model using the classical PSHA approach (Cornell, 1968; McGuire, 1976). The use of logic-trees allows for the consideration of uncertainty in the choice of a GMPE model for the different tectonic region types in the region and in the choice of vulnerability functions for the different taxonomy types in the exposure model.

3.2.6 Event-based risk

This calculator employs an event-based Monte Carlo simulation approach to probabilistic risk assessment in order to estimate the loss distribution for individual assets and aggregated loss distribution for a spatially distributed portfolio of assets within a specified time period. The calculator requires the definition of an exposure model, a vulnerability model for each loss type of interest with vulnerability functions for each taxonomy represented in the exposure model,

and a set of ground motion fields representative of the seismicity of the region over the specified time period. Loss curves and loss maps can currently be calculated for five different loss types using this calculator: structural losses, nonstructural losses, contents losses, downtime losses, and occupant fatalities. The main results of this calculator are loss exceedance curves for each asset, which describe the probability of exceedance of different loss levels over the specified time period, and loss maps for the region, which describe the loss values that have a given probability of exceedance over the specified time period. Aggregate loss exceedance curves can be also be produced using this calculator; these describe the probability of exceedance of different loss levels for all assets of a single taxonomy, or for all assets in the portfolio, over the specified time period. Finally, event loss tables can be produced using this calculator; these tables describe the total loss across the portfolio for each seismic event in the stochastic event set.

This calculator relies on the probabilistic event-based hazard calculator, which simulates the seismicity of the chosen time period T by producing a *stochastic event set* (also known as a *synthetic catalog*). For each rupture generated by a source, the number of occurrences in the given time span T is simulated by sampling the corresponding probability distribution as given by $P_{rup}(k|T)$. A stochastic event set is therefore a *sample* of the full population of ruptures as defined by a seismic source model. Each rupture is present zero, one or more times, depending on its probability. Symbolically, we can define a stochastic event set (*SES*) as:

$$SES(T) = \{k \times rup, k \sim P_{rup}(k|T) \ \forall rup \text{ in } Src \ \forall Src \text{ in } SSM\} \quad (3.3)$$

where k , the number of occurrences, is a random sample of $P_{rup}(k|T)$, and $k \times rup$ means that rupture rup is repeated k times in the stochastic event set.

For each event in the stochastic event sets, a spatially correlated ground motion field (GMF) realisation is generated, taking into consideration both the inter-event variability of ground motions, and the intra-event residuals obtained from a spatial correlation model for ground motion residuals. The use of logic-trees allows for the consideration of uncertainty in the choice of a seismic source model, in the choice of GMPE models for the different tectonic regions, and in the choice of vulnerability functions for the different taxonomy types in the exposure model.

For each GMF realization, a loss ratio is sampled for every asset in the exposure model using the provided probabilistic vulnerability model, taking into consideration the correlation model for vulnerability of different assets of a given taxonomy. Finally loss exceedance curves are computed for both ground-up losses and insured losses.

Scenario Risk Calculator

- Single asset tests
- Multiple asset tests
- Calculation with logic-trees
- Insurance tests

Scenario Damage Calculator

- Single asset tests
- Multiple asset tests
- Calculation with logic-trees

Classical Risk Calculator

- Single asset tests
- Multiple asset tests
- Calculation with logic-trees
- Insurance tests

Classical Damage Calculator

- Single asset tests
- Multiple asset tests
- Calculation with logic-trees

Event-Based Risk Calculator

- Single asset tests
- Multiple asset tests
- Calculation with logic-trees
- Insurance tests

4. Test Cases and Results

4.1 Scenario Risk Calculator

The tests for the scenario risk calculator assume the correct computation of the ground motion fields at the locations of the assets in the exposure model. Thus, the risk tests implicitly rely on the acceptance tests for the scenario hazard calculator.

The rupture model used for the tests comprises a magnitude $M_W 6.7$ rupture on a vertical strike-slip fault.

Details of the rupture are given below:

Fault type: Strike slip

Fault dip: 90°

Fault plane depths: 0–20 km

Fault coordinates:

South end: $38.0000^\circ N$, $122.0000^\circ W$

North end: $38.2248^\circ N$, $122.0000^\circ W$

Rupture magnitude: 6.7

Rupture hypocenter: $38.1124^\circ N$, $122.0000^\circ W$

Hypocenter depth: 10 km

The complete collection of input models and job configuration files used in these test cases can be accessed here: https://github.com/gem/oq-risklib/tree/master/openquake/qa_tests_data/scenario_risk

4.1.1 Single asset tests

Site	Taxonomy	Latitude	Longitude	Comment
1	Wood	38.113	-122.000	On fault midpoint, along strike

Table 4.1 – Asset location and taxonomy for the single-asset test cases

The single asset test cases are designed to test the basic elements of the scenario risk calculator, such as:

- basic loss field computation
- calculation of mean and standard deviation of scenario loss

The location and taxonomy of the single asset in the exposure model used for the single-asset test cases for the scenario risk calculator are given in Table 4.1.

4.1.1.1 Case 1a

Test case 1a uses a set of 10,000 identical ground motion values. There is no uncertainty in the vulnerability function used for this case. The coefficient of variation of the loss ratio is zero at all intensity measure levels.

The purpose of this case is to test the accurate computation of the mean and standard deviation of the loss, given zero variability in both the ground motion values and in the vulnerability function.

GMF #	Site	IMT	GMV
1	1	PGA	0.5000
2	1	PGA	0.5000
3	1	PGA	0.5000
4	1	PGA	0.5000
⋮	⋮	⋮	⋮
10000	1	PGA	0.5000

Table 4.2 – Ground motion fields for the test cases 1a and 1b

Table 4.30 lists five of the ten thousand ground motion values used in this test case.

PGA	0.05	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
Mean LR	0.01	0.04	0.10	0.20	0.33	0.50	0.67	0.80	0.90	0.96	0.99
CoV LR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.3 – Vulnerability function for scenario risk test case 1a

Table 4.31 shows the mean loss ratios and corresponding coefficients of variation in the vulnerability function used in this test case.

Since all ground motion values are identical and there is no variability in the loss ratio, calculation of the loss ratios is straightforward in this case. The ground motion value at the location of the single asset is $PGA = 0.5g$. The vulnerability function for this case provides mean loss ratio values at intensity measure levels 0.4g and 0.6g, but none at 0.5g. The mean loss ratios at 0.4g and 0.6g are 0.10 and 0.20 respectively.

The mean loss ratio at 0.5g is obtained by interpolating between these two values. Linear interpolation gives a mean loss ratio of 0.15 for $PGA = 0.5g$. Since there is no variability in the ground motion, the mean loss ratio is also 0.15, and the standard deviation of the loss ratio is 0.0.

These numbers are multiplied by the asset value of 10,000 to give the mean and standard deviation of loss for the scenario as 1,500 and 0 respectively.

Table 4.4 shows the comparison of the OpenQuake result with the expected result.

Result	Expected	OpenQuake	Difference
Mean loss	1,500	1,500	0%
Std. loss	0	0	0%

Table 4.4 – Results for scenario risk test case 1a**4.1.1.2 Case 1b**

Test case 1b uses the same set of identical ground motion values as case 1a, and described in Table 4.30. However, in contrast to case 1a, variability in the loss ratio is considered in the vulnerability function for this case.

PGA	0.05	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
Mean LR	0.01	0.04	0.10	0.20	0.33	0.50	0.67	0.80	0.90	0.96	0.99
CoV LR	0.03	0.12	0.24	0.32	0.38	0.40	0.38	0.32	0.24	0.12	0.03

Table 4.5 – Vulnerability function for scenario risk test case 1b

Table 4.33 shows the mean loss ratios and corresponding coefficients of variation in the vulnerability function used in this test case.

Similar to case 1a described above, linear interpolation gives a mean loss ratio of 0.15 for $PGA = 0.5g$. The vulnerability function for this case provides coefficients of variation for the loss ratio at intensity measure levels 0.4g and 0.6g, but none at 0.5g. The CoVs of the loss ratio at 0.4g and 0.6g are 0.24 and 0.32 respectively. The coefficient of variation of the loss ratio for $PGA = 0.5g$ is thus obtained by linear interpolation as 0.28.

The loss ratio at $PGA = 0.5g$ follows a lognormal distribution with a mean of 0.15 and a standard deviation of $0.28 \times 0.15 = 0.042$.

Since there is no variability in the ground motion, the mean loss ratio for the scenario is also 0.15, and the standard deviation of the loss ratio is 0.042.

These numbers are multiplied by the asset value of 10,000 to give the mean and standard deviation of loss for the scenario as 1,500 and 420 respectively.

Result	Expected	OpenQuake	Difference
Mean loss	1,500	1491.15	0.59%
Std. loss	420	413.36	1.58%

Table 4.6 – Results for scenario risk test case 1b

Table 4.6 shows the comparison of the OpenQuake result with the expected result.

4.1.1.3 Case 1c

Variability in the ground motion is considered in all cases starting from case 1c. Ten thousand ground motion fields are generated for the given rupture, taking into consideration both the inter-event and intra-event variability in the ground motion. The ground motion prediction equation used is Boore and Atkinson (2008).

The purpose of this case is to test the computation of the mean and standard deviation of the loss, given variability in both the ground motion values and no variability in the vulnerability function.

Table 4.35 lists five of the ten thousand ground motion values generated by OpenQuake.

Since the mean loss ratios in the vulnerability function are not a linear function of the intensity measure levels, an analytical solution for the mean and standard deviation of loss

GMF	Site	IMT	GMV
1	1	PGA	1.3495
2	1	PGA	0.5393
3	1	PGA	0.5240
4	1	PGA	1.0385
⋮	⋮	⋮	⋮
10000	1	PGA	0.1327

Table 4.7 – Ground motion fields for the single asset tests

for the scenario cannot be found. Thus, in order to check the OpenQuake results, an alternate implementation of the calculator algorithm in the programming language Julia is used.

The mean and standard deviation of the logarithm of the ground motion calculated at the location of the asset as obtained by using the Boore and Atkinson (2008) equation are -0.648 and 0.564 respectively. Assuming a lognormal distribution for the variability in the ground motion, one million ground motion values are generated using Julia with these logarithmic mean and standard deviation values.

The variability in the loss ratios is zero for the vulnerability function used in this test case. Thus, the loss ratio for each simulated ground motion value is obtained through interpolation on the mean loss ratios provided by the vulnerability function. The mean and standard deviation of loss ratio for the scenario are estimated simply as the mean and standard deviation of the million simulated loss ratios.

Result	Expected	OpenQuake	Difference
Mean loss	2,406.35	2,381.29	0.62%
Std. loss	2,181.39	2,169.72	0.53%

Table 4.8 – Results for scenario risk test case 1c

Table 4.8 shows the comparison of the OpenQuake result with the expected result.

4.1.1.4 Case 1d

The purpose of this case is to test the computation of the mean and standard deviation of the loss, given variability in both the ground motion values and in the vulnerability function.

Similar to case 1c, one million ground motion values are generated using Julia with the logarithmic mean and standard deviation of the ground motion value at the location of the asset as obtained by using the Boore and Atkinson (2008).

The mean loss ratio and standard deviation of loss ratio for each simulated ground motion value are obtained through interpolation on the mean loss ratios and corresponding coefficients of variation provided by the vulnerability function. Using the interpolated mean and standard deviation of loss ratios, one loss ratio is sampled for each ground motion value, assuming a lognormal distribution.

The mean and standard deviation of loss ratio for the scenario are estimated simply as the mean and standard deviation of the million simulated loss ratios.

Result	Expected	OpenQuake	Difference
Mean loss	2,383.1	2,370.7	0.52%
Std. loss	2,419.3	2,401.7	0.72%

Table 4.9 – Results for scenario risk test case 1d

Table 4.9 shows the comparison of the OpenQuake result with the expected result.

4.1.1.5 Case 1e

Result	Expected	OpenQuake	Difference
Mean loss	2395.89	2383.52	0.52%
Std. loss	2178.93	2163.8	0.69%

Table 4.10 – Results for scenario risk test case 1e

Table 4.10 shows the comparison of the OpenQuake result with the expected result.

4.1.1.6 Case 1f

Result	Expected	OpenQuake	Difference
Mean loss	2398.93		%
Std. loss	2414.73		%

Table 4.11 – Results for scenario risk test case 1f

Table 4.11 shows the comparison of the OpenQuake result with the expected result.

4.1.1.7 Case 2a

Result	Expected	OpenQuake	Difference
Mean loss	4265.39	4232.00	0.78%
Std. loss	3895.89	3880.37	0.4%

Table 4.12 – Results for scenario risk test case 2a

Table 4.12 shows the comparison of the OpenQuake result with the expected result.

4.1.1.8 Case 2b

Table 4.13 shows the comparison of the OpenQuake result with the expected result.

4.1.1.9 Case 2c

Table 4.14 shows the comparison of the OpenQuake result with the expected result.

4.1.1.10 Case 2d

Table 4.15 shows the comparison of the OpenQuake result with the expected result.

4.1.1.11 Case 2e

Table 4.16 shows the comparison of the OpenQuake result with the expected result.

4.1.1.12 Case 3a

Table 4.17 shows the comparison of the OpenQuake result with the expected result.

4.1.1.13 Case 4a

Table 4.18 shows the comparison of the OpenQuake result with the expected result.

4.1.1.14 Case 4b

Table 4.19 shows the comparison of the OpenQuake result with the expected result.

4.1.1.15 Case 4c

Table 4.20 shows the comparison of the OpenQuake result with the expected result.

Result	Expected	OpenQuake	Difference
Mean loss	2783.81	2761.30	0.81%
Std. loss	1591.15	1585.84	0.33%

Table 4.13 – Results for scenario risk test case 2b

Result	Expected	OpenQuake	Difference
Mean loss	479.57		%
Std. loss	482.72		%

Table 4.14 – Results for scenario risk test case 2c

Result	Expected	OpenQuake	Difference
Mean loss	0.0144	0.0143	0.80%
Std. loss	0.0145	0.0144	0.41%

Table 4.15 – Results for scenario risk test case 2d

Result	Expected	OpenQuake	Difference
Mean loss	0.0048	0.0048	0.92%
Std. loss	0.0048	0.0048	0.49%

Table 4.16 – Results for scenario risk test case 2e

Result	Expected	OpenQuake	Difference
Mean loss	1798.25	1783.93	0.80%
Std. loss	1808.36	1804.20	0.23%

Table 4.17 – Results for scenario risk test case 3a

Result	Expected	OpenQuake	Difference
Mean loss	4797.71		%
Std. loss	4829.23		%

Table 4.18 – Results for scenario risk test case 4a

Result	Expected	OpenQuake	Difference
Mean loss	3597.93	3567.87	0.84%
Std. loss	3618.99	3608.39	0.29%

Table 4.19 – Results for scenario risk test case 4b

Result	Expected	OpenQuake	Difference
Mean loss	1200.51	2378.58	-98.13%
Std. loss	1209.25	2405.59	-98.93%

Table 4.20 – Results for scenario risk test case 4c

4.1.1.16 Case 4d

Result	Expected	OpenQuake	Difference
Mean loss	9603.52	9514.31	0.93%
Std. loss	9657.50	9622.38	0.36%

Table 4.21 – *Results for scenario risk test case 4d*

Table 4.21 shows the comparison of the OpenQuake result with the expected result.

4.1.2 Multiple asset tests

Site	Taxonomy	Latitude	Longitude	Comment
1	Wood	38.113	-122.000	On fault midpoint, along strike
2	Wood	38.113	-122.114	10 km west of fault, at midpoint
3	RC	38.113	-122.570	50 km west of fault, at midpoint
4	RC	38.000	-122.000	South end of fault
5	Steel	37.910	-122.000	10 km south of fault, along strike
6	Wood	38.225	-122.000	North end of fault
7	Steel	38.113	-121.886	10 km east of fault, at midpoint

Table 4.22 – Asset sites and taxonomies for the multiple-asset test cases

The multiple asset test cases are designed to test the loss aggregation functions of the scenario risk calculator, such as:

- portfolio loss computation for a given ground motion field
- calculation of mean and standard deviation of portfolio scenario loss

The list of assets in the exposure model used for the multiple-asset test cases for the scenario risk calculator is given in Table 4.75.

Ten thousand ground motion fields are generated for the given rupture, taking into consideration both the inter-event and intra-event variability in the ground motion. The ground motion prediction equation used is Boore and Atkinson (2008), and the Jayaram and Baker (2009) model for spatial correlation of ground motion values is applied.

GMF	Site	IMT	GMV
1	1	PGA	1.125
1	2	PGA	0.261
1	3	PGA	0.073
1	4	PGA	0.756
1	5	PGA	0.121
1	6	PGA	0.671
1	7	PGA	0.274
2	1	PGA	0.386
2	2	PGA	0.198
2	3	PGA	0.058
2	4	PGA	0.660
2	5	PGA	0.396
2	6	PGA	0.529
2	7	PGA	0.297
⋮	⋮	⋮	⋮
10,000	1	PGA	0.265
10,000	2	PGA	0.106
10,000	3	PGA	0.114
10,000	4	PGA	0.213
10,000	5	PGA	0.293
10,000	6	PGA	0.639
10,000	7	PGA	0.093

Table 4.23 – Ground motion fields for the multiple asset tests

Table 4.40 lists three of the ten thousand ground motion fields generated.

4.1.2.1 Case 5a

The purpose of this case is to test the computation of the mean and standard deviation of the loss for multiple assets, given variability in both the ground motion values and in the vulnerability function. The computation of the mean and standard deviation of the portfolio loss is also tested in this case. The asset vulnerability correlation factor is zero for this test case.

Asset	Result	Expected	OpenQuake	Difference
a1	Mean loss			%
	Std. loss			%
a2	Mean loss			%
	Std. loss			%
a3	Mean loss			%
	Std. loss			%
a4	Mean loss			%
	Std. loss			%
a5	Mean loss			%
	Std. loss			%
a6	Mean loss			%
	Std. loss			%
a7	Mean loss			%
	Std. loss			%
Total	Mean loss			%
	Std. loss			%

Table 4.24 – Results for scenario risk test case 5a

Table 4.24 shows the comparison of the OpenQuake result with the expected result.

4.1.2.2 Case 5b

Table 4.25 shows the comparison of the OpenQuake result with the expected result.

4.1.2.3 Case 5c

Table 4.26 shows the comparison of the OpenQuake result with the expected result.

4.1.2.4 Case 5d

Table 4.27 shows the comparison of the OpenQuake result with the expected result.

Asset	Result	Expected	OpenQuake	Difference
a1	Mean loss	2397.7	2,388.0	0.0%
	Std. loss	2406.7	2404.9	0.0%
a2	Mean loss	629.8		0.0%
	Std. loss	691.1		0.0%
a3	Mean loss	149.1	150.1	0.0%
	Std. loss	135.2	129.9	0.0%
a4	Mean loss	2405.5	2387.3	0.0%
	Std. loss	2428.2	2389.3	0.0%
a5	Mean loss	627.9	619.9	0.0%
	Std. loss	687.7	632.9	0.0%
a6	Mean loss	2096.6	2091.7	0.0%
	Std. loss	2200.4	2208.5	0.0%
a7	Mean loss	628.3	692.7	0.0%
	Std. loss	627.4	684.4	0.0%
Total	Mean loss	8934.6	8889.2	0.0%
	Std. loss	4241.2	6238.1	0.0%

Table 4.25 – Results for scenario risk test case 5b

Asset	Result	Expected	OpenQuake	Difference
a1	Mean loss			0.0%
	Std. loss			0.0%
a2	Mean loss			0.0%
	Std. loss			0.0%
a3	Mean loss			0.0%
	Std. loss			0.0%
a4	Mean loss			0.0%
	Std. loss			0.0%
a5	Mean loss			0.0%
	Std. loss			0.0%
a6	Mean loss			0.0%
	Std. loss			0.0%
a7	Mean loss			0.0%
	Std. loss			0.0%
Total	Mean loss			0.0%
	Std. loss			0.0%

Table 4.26 – Results for scenario risk test case 5c

Asset	Result	Expected	OpenQuake	Difference
a1	Mean loss			%
	Std. loss			%
a2	Mean loss			%
	Std. loss			%
a3	Mean loss			%
	Std. loss			%
a4	Mean loss			%
	Std. loss			%
a5	Mean loss			%
	Std. loss			%
a6	Mean loss			%
	Std. loss			%
a7	Mean loss			%
	Std. loss			%
Total	Mean loss			%
	Std. loss			%

Table 4.27 – Results for scenario risk test case 5d

4.1.3 Calculation with logic-trees

4.1.3.1 Case 6a

Branch	Result	Expected	OpenQuake	Difference
b1	Mean loss			%
	Std. loss			%
b2	Mean loss			%
	Std. loss			%
Mean	Mean loss			%
	Std. loss			%

Table 4.28 – *Results for scenario risk test case 6a*

Table 4.28 shows the comparison of the OpenQuake result with the expected result.

4.1.4 Insurance tests

4.1.4.1 Case 7a

Result	Expected	OpenQuake	Difference
Mean insured loss			%
Std. insured loss			%

Table 4.29 – *Results for scenario risk test case 7a*

Table 4.29 shows the comparison of the OpenQuake result with the expected result.

4.2 Scenario Damage Calculator

The tests for the scenario damage calculator assume the correct computation of the ground motion fields at the locations of the assets in the exposure model. Thus, the risk tests implicitly rely on the acceptance tests for the scenario hazard calculator.

The rupture model used for the tests comprises a magnitude $M_W 6.7$ rupture on a vertical strike-slip fault.

Details of the rupture are given below:

Fault type: Strike slip

Fault dip: 90°

Fault plane depths: 0–20 km

Fault coordinates:

South end: $38.0000^\circ N$, $122.0000^\circ W$

North end: $38.2248^\circ N$, $122.0000^\circ W$

Rupture magnitude: 6.7

Rupture hypocenter: $38.1124^\circ N$, $122.0000^\circ W$

Hypocenter depth: 10 km

The complete collection of input models and job configuration files used in these test cases can be accessed here: https://github.com/gem/oq-risklib/tree/master/openquake/qa_tests_data/scenario_damage

4.2.1 Single asset tests

The single asset test cases are designed to test the basic elements of the scenario damage calculator, such as:

- basic loss field computation
- calculation of mean and standard deviation of scenario loss

The location and taxonomy of the single asset in the exposure model used for the single-asset test cases for the scenario risk calculator are given in Table 4.1.

4.2.1.1 Case 1a

Test case 1a uses a set of 10,000 identical ground motion values.

The purpose of this case is to test the accurate computation of the mean and standard deviation of the probability of occurrence of each damage state over the specified time period, given zero variability in the ground motion values.

GMF #	Site	IMT	GMV
1	1	PGA	0.5000
2	1	PGA	0.5000
3	1	PGA	0.5000
4	1	PGA	0.5000
⋮	⋮	⋮	⋮
10000	1	PGA	0.5000

Table 4.30 – Ground motion fields for the test cases 1a and 1b

Table 4.30 lists five of the ten thousand ground motion values used in this test case.

PGA	0.05	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
Mean LR	0.01	0.04	0.10	0.20	0.33	0.50	0.67	0.80	0.90	0.96	0.99
CoV LR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.31 – Vulnerability function for scenario risk test case 1a

Table 4.31 shows the mean loss ratios and corresponding coefficients of variation in the vulnerability function used in this test case.

Since all ground motion values are identical and there is no variability in the loss ratio, calculation of the loss ratios is straightforward in this case. The ground motion value at the location of the single asset is $PGA = 0.5g$. The vulnerability function for this case provides mean loss ratio values at intensity measure levels 0.4g and 0.6g, but none at 0.5g. The mean loss ratios at 0.4g and 0.6g are 0.10 and 0.20 respectively.

The mean loss ratio at 0.5g is obtained by interpolating between these two values. Linear interpolation gives a mean loss ratio of 0.15 for $PGA = 0.5g$. Since there is no variability in the ground motion, the mean loss ratio is also 0.15, and the standard deviation of the loss ratio is 0.0.

These numbers are multiplied by the asset value of 10,000 to give the mean and standard deviation of loss for the scenario as 1,500 and 0 respectively.

Table 4.32 shows the comparison of the OpenQuake result with the expected result.

4.2.1.2 Case 1b

Test case 1b uses the same set of identical ground motion values as case 1a, and described in Table 4.30. However, in contrast to case 1a, variability in the loss ratio is considered in the vulnerability function for this case.

Table 4.33 shows the mean loss ratios and corresponding coefficients of variation in the vulnerability function used in this test case.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.32 – Results for scenario damage test case 1a

PGA	0.05	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
Mean LR	0.01	0.04	0.10	0.20	0.33	0.50	0.67	0.80	0.90	0.96	0.99
CoV LR	0.03	0.12	0.24	0.32	0.38	0.40	0.38	0.32	0.24	0.12	0.03

Table 4.33 – Vulnerability function for scenario risk test case 1b

Similar to case 1a described above, linear interpolation gives a mean loss ratio of 0.15 for $PGA = 0.5g$. The vulnerability function for this case provides coefficients of variation for the loss ratio at intensity measure levels 0.4g and 0.6g, but none at 0.5g. The CoVs of the loss ratio at 0.4g and 0.6g are 0.24 and 0.32 respectively. The coefficient of variation of the loss ratio for $PGA = 0.5g$ is thus obtained by linear interpolation as 0.28.

The loss ratio at $PGA = 0.5g$ follows a lognormal distribution with a mean of 0.15 and a standard deviation of $0.28 \times 0.15 = 0.042$.

Since there is no variability in the ground motion, the mean loss ratio for the scenario is also 0.15, and the standard deviation of the loss ratio is 0.042.

These numbers are multiplied by the asset value of 10,000 to give the mean and standard deviation of loss for the scenario as 1,500 and 420 respectively.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.34 – Results for scenario damage test case 1b

Table 4.34 shows the comparison of the OpenQuake result with the expected result.

4.2.1.3 Case 1c

Variability in the ground motion is considered in all cases starting from case 1c. Ten thousand ground motion fields are generated for the given rupture, taking into consideration both the

inter-event and intra-event variability in the ground motion. The ground motion prediction equation used is Boore and Atkinson (2008).

The purpose of this case is to test the computation of the mean and standard deviation of the loss, given variability in both the ground motion values and no variability in the vulnerability function.

GMF	Site	IMT	GMV
1	1	PGA	1.3495
2	1	PGA	0.5393
3	1	PGA	0.5240
4	1	PGA	1.0385
⋮	⋮	⋮	⋮
10000	1	PGA	0.1327

Table 4.35 – Ground motion fields for the single asset tests

Table 4.35 lists five of the ten thousand ground motion values generated by OpenQuake.

Since the mean loss ratios in the vulnerability function are not a linear function of the intensity measure levels, an analytical solution for the mean and standard deviation of loss for the scenario cannot be found. Thus, in order to check the OpenQuake results, an alternate implementation of the calculator algorithm in the programming language Julia is used.

The mean and standard deviation of the logarithm of the ground motion calculated at the location of the asset as obtained by using the Boore and Atkinson (2008) equation are -0.648 and 0.564 respectively. Assuming a lognormal distribution for the variability in the ground motion, one million ground motion values are generated using Julia with these logarithmic mean and standard deviation values.

The variability in the loss ratios is zero for the vulnerability function used in this test case. Thus, the loss ratio for each simulated ground motion value is obtained through interpolation on the mean loss ratios provided by the vulnerability function. The mean and standard deviation of loss ratio for the scenario are estimated simply as the mean and standard deviation of the million simulated loss ratios.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.36 – Results for scenario damage test case 1c

Table 4.36 shows the comparison of the OpenQuake result with the expected result.

4.2.1.4 Case 1d

The purpose of this case is to test the computation of the mean and standard deviation of the loss, given variability in both the ground motion values and in the vulnerability function.

Similar to case 1c, one million ground motion values are generated using Julia with the logarithmic mean and standard deviation of the ground motion value at the location of the asset as obtained by using the Boore and Atkinson (2008).

The mean loss ratio and standard deviation of loss ratio for each simulated ground motion value are obtained through interpolation on the mean loss ratios and corresponding coefficients of variation provided by the vulnerability function. Using the interpolated mean and standard deviation of loss ratios, one loss ratio is sampled for each ground motion value, assuming a lognormal distribution.

The mean and standard deviation of loss ratio for the scenario are estimated simply as the mean and standard deviation of the million simulated loss ratios.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.37 – Results for scenario damage test case 1d

Table 4.37 shows the comparison of the OpenQuake result with the expected result.

4.2.1.5 Case 2a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.38 – Results for scenario damage test case 2a

Table 4.38 shows the comparison of the OpenQuake result with the expected result.

4.2.1.6 Case 3a

Table 4.39 shows the comparison of the OpenQuake result with the expected result.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.39 – Results for scenario damage test case 3a

4.2.2 Multiple asset tests

The multiple asset test cases are designed to test the loss aggregation functions of the scenario damage calculator, such as:

- damage distribution per taxonomy
- damage distribution for the portfolio

The list of assets in the exposure model used for the multiple-asset test cases for the scenario damage calculator is given in Table 4.75.

Ten thousand ground motion fields are generated for the given rupture, taking into consideration both the inter-event and intra-event variability in the ground motion. The ground motion prediction equation used is Boore and Atkinson (2008), and the Jayaram and Baker (2009) model for spatial correlation of ground motion values is applied.

GMF	Site	IMT	GMV
1	1	PGA	1.125
1	2	PGA	0.261
1	3	PGA	0.073
1	4	PGA	0.756
1	5	PGA	0.121
1	6	PGA	0.671
1	7	PGA	0.274
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2	1	PGA	0.386
2	2	PGA	0.198
2	3	PGA	0.058
2	4	PGA	0.660
2	5	PGA	0.396
2	6	PGA	0.529
2	7	PGA	0.297
<hr/>			
⋮	⋮	⋮	⋮
<hr/>			
10,000	1	PGA	0.265
10,000	2	PGA	0.106
10,000	3	PGA	0.114
10,000	4	PGA	0.213
10,000	5	PGA	0.293
10,000	6	PGA	0.639
10,000	7	PGA	0.093

Table 4.40 – *Ground motion fields for the multiple asset tests*

Table 4.40 lists three of the ten thousand ground motion fields generated.

4.2.2.1 Case 4a

The purpose of this case is to test the computation of the mean and standard deviation of the number of buildings in each damage state, given variability in the ground motion values. The computation of the mean and standard deviation of the portfolio loss is also tested in this case.

Table 4.41 shows the comparison of the OpenQuake result with the expected result.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.41 – Results for scenario damage test case 4a

4.2.3 Calculation with logic-trees

4.2.3.1 Case 5a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Mean			%
		Std.			%
	Slight	Mean			%
		Std.			%
	Moderate	Mean			%
		Std.			%
	Extreme	Mean			%
		Std.			%
	Complete	Mean			%
		Std.			%

Table 4.42 – *Results for scenario damage test case 5a*

Table 4.42 shows the comparison of the OpenQuake results with the expected results.

4.3 Classical Risk Calculator

The tests for the classical PSHA-based risk calculator assume the correct computation of the hazard curves at the locations of the assets in the exposure model. Thus, the risk tests implicitly rely on the acceptance tests for the classical PSHA-based hazard calculator.

The source model used for the tests comprises a single vertical strike-slip fault with a Gutenberg-Richter b -value equal to 0.9 and a slip rate of 2 mm/yr. The MFD is a Gutenberg-Richter distribution truncated between magnitudes 5.0 and 6.5, while the Ground Motion Prediction Equation (GMPE) used is Sadigh et al. (1997), with sigma set to zero.

Details of the fault geometry are given below:

Fault type: Strike slip

Fault dip: 90°

Fault plane depths: 0–12 km

Fault coordinates:

South end: $38.0000^\circ N$, $122.0000^\circ W$

North end: $38.2248^\circ N$, $122.0000^\circ W$

The complete collection of input models and job configuration files used in these test cases can be accessed here: https://github.com/gem/oq-risklib/tree/master/openquake/qa_tests_data/classical_risk

4.3.1 Single asset tests

The single asset test cases are designed to test the basic elements of the classical-PSHA based risk calculator, such as:

- asset loss ratio exceedance curve computation
- asset loss exceedance curve computation

The location and taxonomy of the single asset in the exposure model used for the single-asset test cases for the classical risk calculator are given in Table 4.75.

4.3.1.1 Case 1a

Test case 1a

Result	Expected	OpenQuake	Difference
Average loss	59.70	59.70	0%

Table 4.43 – Results for classical risk test case 1a

Table 4.43 shows the comparison of the OpenQuake result with the expected result.

4.3.1.2 Case 1b

Test case 1b

Result	Expected	OpenQuake	Difference
Average loss	45.55	45.55	0%

Table 4.44 – Results for classical risk test case 1b

Table 4.44 shows the comparison of the OpenQuake result with the expected result.

4.3.1.3 Case 1c

Result	Expected	OpenQuake	Difference
Average loss	43.73	43.73	0%

Table 4.45 – Results for classical risk test case 1c

Table 4.45 shows the comparison of the OpenQuake result with the expected result.

4.3.1.4 Case 1d

Table 4.46 shows the comparison of the OpenQuake result with the expected result.

4.3.1.5 Case 1e

Table 4.47 shows the comparison of the OpenQuake result with the expected result.

4.3.1.6 Case 2a

Table 4.48 shows the comparison of the OpenQuake result with the expected result.

4.3.1.7 Case 2b

Table 4.49 shows the comparison of the OpenQuake result with the expected result.

4.3.1.8 Case 2c

Table 4.50 shows the comparison of the OpenQuake result with the expected result.

4.3.1.9 Case 2d

Table 4.51 shows the comparison of the OpenQuake result with the expected result.

Result	Expected	OpenQuake	Difference
Average loss	59.70	59.70	0%

Table 4.46 – Results for classical risk test case 1d

Result	Expected	OpenQuake	Difference
Average loss	46.07	46.07	0%

Table 4.47 – Results for classical risk test case 1e

Result	Expected	OpenQuake	Difference
Average loss	82.25	82.25	0%

Table 4.48 – Results for classical risk test case 2a

Result	Expected	OpenQuake	Difference
Average loss	59.60	59.60	0%

Table 4.49 – Results for classical risk test case 2b

Result	Expected	OpenQuake	Difference
Average loss	9.11	9.11	0%

Table 4.50 – Results for classical risk test case 2c

Result	Expected	OpenQuake	Difference
Average loss	8.78×10^{-4}	8.78×10^{-4}	0%

Table 4.51 – Results for classical risk test case 2d

Result	Expected	OpenQuake	Difference
Average loss	34.44	34.44	0%

Table 4.52 – Results for classical risk test case 3a

4.3.1.10 Case 3a

Table 4.52 shows the comparison of the OpenQuake result with the expected result.

4.3.1.11 Case 4a

Result	Expected	OpenQuake	Difference
Average loss	45.55	45.55	0%

Table 4.53 – Results for classical risk test case 4a

Table 4.53 shows the comparison of the OpenQuake result with the expected result.

4.3.1.12 Case 4b

Result	Expected	OpenQuake	Difference
Average loss	2115.81	2115.81	0%

Table 4.54 – Results for classical risk test case 4b

Table 4.54 shows the comparison of the OpenQuake result with the expected result.

4.3.1.13 Case 4c

Result	Expected	OpenQuake	Difference
Average loss	2115.81	2115.81	0%

Table 4.55 – Results for classical risk test case 4c

Table 4.55 shows the comparison of the OpenQuake result with the expected result.

4.3.1.14 Case 5a

Table 4.56 shows the comparison of the OpenQuake result with the expected result.

4.3.1.15 Case 5b

Table 4.57 shows the comparison of the OpenQuake result with the expected result.

4.3.1.16 Case 5c

Table 4.58 shows the comparison of the OpenQuake result with the expected result.

4.3.1.17 Case 5d

Table 4.59 shows the comparison of the OpenQuake result with the expected result.

Result	Expected	OpenQuake	Difference
Average loss	91.10	91.10	0%

Table 4.56 – *Results for classical risk test case 5a*

Result	Expected	OpenQuake	Difference
Average loss	68.32	68.32	0%

Table 4.57 – *Results for classical risk test case 5b*

Result	Expected	OpenQuake	Difference
Average loss	22.77	22.77	0%

Table 4.58 – *Results for classical risk test case 5c*

Result	Expected	OpenQuake	Difference
Average loss	18.22	18.22	0%

Table 4.59 – *Results for classical risk test case 5d*

4.3.2 Multiple asset tests

The multiple asset test cases are designed to test the correct working of the classical risk calculator for a portfolio of assets of different taxonomies. The vulnerability functions for the different taxonomies are based on different intensity measure types.

The list of assets in the exposure model used for the multiple-asset test cases for the classical risk calculator is given in Table 4.75.

4.3.2.1 Case 6a

Asset	Result	Expected	OpenQuake	Difference
a1	Average loss	45.55	45.55	0%
a2	Average loss	19.10	19.10	0%
a3	Average loss	1.06	1.04	0%
a4	Average loss	28.33	28.33	0%
a5	Average loss	11.89	11.89	0%
a6	Average loss	28.29	28.29	0%
a7	Average loss	19.10	19.10	0%

Table 4.60 – Results for classical risk test case 6a

Table 4.60 shows the comparison of the OpenQuake results with the expected results.

4.3.3 Calculation with logic-trees

4.3.3.1 Case 7a

Branch	Asset	Result	Expected	OpenQuake	Difference
b1	a1	Average loss			0%
b2	a1	Average loss			0%

Table 4.61 – *Results for classical risk test case 7a*

Table 4.61 shows the comparison of the OpenQuake result with the expected result.

4.3.4 Insurance tests

4.3.4.1 Case 8a

Result	Expected	OpenQuake	Difference
Average insured loss			0%

Table 4.62 – *Results for classical risk test case 8a*

Table 4.62 shows the comparison of the OpenQuake result with the expected result.

4.4 Classical Damage Calculator

The tests for the classical PSHA-based damage calculator assume the correct computation of the hazard curves at the locations of the assets in the exposure model. Thus, the damage tests implicitly rely on the acceptance tests for the classical PSHA-based hazard calculator.

The source model used for the tests comprises a single vertical strike-slip fault with a Gutenberg-Richter b -value equal to 0.9 and a slip rate of 2 mm/yr. The MFD is a Gutenberg-Richter distribution truncated between magnitudes 5.0 and 6.5, while the Ground Motion Prediction Equation (GMPE) used is Sadigh et al. (1997), with sigma set to zero.

Details of the fault geometry are given below:

Fault type: Strike slip

Fault dip: 90°

Fault plane depths: 0–12 km

Fault coordinates:

South end: $38.0000^\circ N$, $122.0000^\circ W$

North end: $38.2248^\circ N$, $122.0000^\circ W$

The complete collection of input models and job configuration files used in these test cases can be accessed here: https://github.com/gem/oq-risklib/tree/master/openquake/qa_tests_data/classical_damage

4.4.1 Single asset tests

The single asset test cases are designed to test the basic elements of the classical-PSHA based damage calculator, such as:

- damage state occurrence probabilities for assets

The location and taxonomy of the single asset in the exposure model used for the single-asset test cases for the classical damage calculator are given in Table 4.75.

4.4.1.1 Case 1a

Test case 1a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.71×10^{-1}	9.71×10^{-1}	0%
	Slight	Probability of occurrence	4.88×10^{-3}	4.88×10^{-3}	0%
	Moderate	Probability of occurrence	6.72×10^{-3}	6.72×10^{-3}	0%
	Extreme	Probability of occurrence	5.21×10^{-3}	5.21×10^{-3}	0%
	Complete	Probability of occurrence	1.15×10^{-2}	1.15×10^{-2}	0%

Table 4.63 – Results for classical damage test case 1a

Table 4.63 shows the comparison of the OpenQuake result with the expected result.

4.4.1.2 Case 1b

Test case 1b

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.83×10^{-1}	9.83×10^{-1}	0%
	Slight	Probability of occurrence	1.04×10^{-3}	1.04×10^{-3}	0%
	Moderate	Probability of occurrence	2.89×10^{-3}	2.89×10^{-3}	0%
	Extreme	Probability of occurrence	3.29×10^{-3}	3.29×10^{-3}	0%
	Complete	Probability of occurrence	1.01×10^{-2}	1.01×10^{-2}	0%

Table 4.64 – Results for classical damage test case 1b

Table 4.64 shows the comparison of the OpenQuake result with the expected result.

4.4.1.3 Case 1c

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.72×10^{-1}	9.72×10^{-1}	0%
	Slight	Probability of occurrence	4.78×10^{-3}	4.78×10^{-3}	0%
	Moderate	Probability of occurrence	6.62×10^{-3}	6.62×10^{-3}	0%
	Extreme	Probability of occurrence	5.15×10^{-3}	5.15×10^{-3}	0%
	Complete	Probability of occurrence	1.15×10^{-2}	1.15×10^{-2}	0%

Table 4.65 – Results for classical damage test case 1c

Table 4.65 shows the comparison of the OpenQuake result with the expected result.

4.4.1.4 Case 2a

Table 4.66 shows the comparison of the OpenQuake result with the expected result.

4.4.1.5 Case 2b

Table 4.67 shows the comparison of the OpenQuake result with the expected result.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.71×10^{-1}	9.71×10^{-1}	0%
	Slight	Probability of occurrence	4.53×10^{-3}	4.53×10^{-3}	0%
	Moderate	Probability of occurrence	8.48×10^{-3}	8.48×10^{-3}	0%
	Extreme	Probability of occurrence	5.29×10^{-3}	5.29×10^{-3}	0%
	Complete	Probability of occurrence	1.10×10^{-2}	1.10×10^{-2}	0%

Table 4.66 – Results for classical damage test case 2a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.71×10^{-1}	9.71×10^{-1}	0%
	Slight	Probability of occurrence	4.52×10^{-3}	4.52×10^{-3}	0%
	Moderate	Probability of occurrence	8.48×10^{-3}	8.48×10^{-3}	0%
	Extreme	Probability of occurrence	5.29×10^{-3}	5.29×10^{-3}	0%
	Complete	Probability of occurrence	1.10×10^{-2}	1.10×10^{-2}	0%

Table 4.67 – Results for classical damage test case 2b**4.4.1.6 Case 3a**

Table 4.68 shows the comparison of the OpenQuake result with the expected result.

4.4.1.7 Case 4a

Table 4.69 shows the comparison of the OpenQuake result with the expected result.

4.4.1.8 Case 4b

Table 4.70 shows the comparison of the OpenQuake result with the expected result.

4.4.1.9 Case 4c

Table 4.71 shows the comparison of the OpenQuake result with the expected result.

4.4.1.10 Case 5a

Table 4.72 shows the comparison of the OpenQuake result with the expected result.

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.72×10^{-1}	9.72×10^{-1}	0%
	Slight	Probability of occurrence	8.02×10^{-3}	8.02×10^{-3}	0%
	Moderate	Probability of occurrence	1.06×10^{-2}	1.06×10^{-2}	0%
	Extreme	Probability of occurrence	5.73×10^{-3}	5.73×10^{-3}	0%
	Complete	Probability of occurrence	3.15×10^{-3}	3.15×10^{-3}	0%

Table 4.68 – Results for classical damage test case 3a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	9.71×10^{-1}	9.71×10^{-1}	0%
	Slight	Probability of occurrence	4.43×10^{-3}	4.43×10^{-3}	0%
	Moderate	Probability of occurrence	8.41×10^{-3}	8.41×10^{-3}	0%
	Extreme	Probability of occurrence	5.29×10^{-3}	5.29×10^{-3}	0%
	Complete	Probability of occurrence	1.10×10^{-2}	1.10×10^{-2}	0%

Table 4.69 – Results for classical damage test case 4a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	1.09×10^{-1}	1.09×10^{-1}	0%
	Slight	Probability of occurrence	4.43×10^{-2}	4.43×10^{-2}	0%
	Moderate	Probability of occurrence	1.38×10^{-1}	1.38×10^{-1}	0%
	Extreme	Probability of occurrence	1.44×10^{-1}	1.44×10^{-1}	0%
	Complete	Probability of occurrence	5.65×10^{-1}	5.65×10^{-1}	0%

Table 4.70 – Results for classical damage test case 4b

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence	1.09×10^{-1}	1.09×10^{-1}	0%
	Slight	Probability of occurrence	4.43×10^{-2}	4.43×10^{-2}	0%
	Moderate	Probability of occurrence	1.38×10^{-1}	1.38×10^{-1}	0%
	Extreme	Probability of occurrence	1.44×10^{-1}	1.44×10^{-1}	0%
	Complete	Probability of occurrence	5.65×10^{-1}	5.65×10^{-1}	0%

Table 4.71 – Results for classical damage test case 4c

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Expected number of buildings			%
	Slight	Expected number of buildings			%
	Moderate	Expected number of buildings			%
	Extreme	Expected number of buildings			%
	Complete	Expected number of buildings			%

Table 4.72 – Results for classical damage test case 5a

4.4.2 Multiple asset tests

The multiple asset test cases are designed to test the correct working of the classical risk calculator for a portfolio of assets of different taxonomies. The vulnerability functions for the different taxonomies are based on different intensity measure types.

The list of assets in the exposure model used for the multiple-asset test cases for the classical risk calculator is given in Table 4.75.

4.4.2.1 Case 6a

Asset	Damage State	Result	Expected	OpenQuake	Difference
a1	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a2	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a3	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a4	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a5	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a6	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%
a7	No damage	Probability of occurrence			%
	Slight	Probability of occurrence			%
	Moderate	Probability of occurrence			%
	Extreme	Probability of occurrence			%
	Complete	Probability of occurrence			%

Table 4.73 – Results for classical damage test case 7a

Table ?? shows the comparison of the OpenQuake result with the expected result.

4.4.3 Calculation with logic-trees

4.4.3.1 Case 7a

Branch	Asset	Damage State	Result	Expected	OpenQuake	Difference
b1	a1	No damage	Probability of occurrence			
	Slight	Probability of occurrence			%	
	Moderate	Probability of occurrence			%	
	Extreme	Probability of occurrence			%	
	Complete	Probability of occurrence			%	
b2	a1	No damage	Probability of occurrence			
	Slight	Probability of occurrence			%	
	Moderate	Probability of occurrence			%	
	Extreme	Probability of occurrence			%	
	Complete	Probability of occurrence			%	

Table 4.74 – Results for classical damage test case 7a

Table 4.74 shows the comparison of the OpenQuake result with the expected result.

Site	Taxonomy	Latitude	Longitude	Comment
1	Wood	38.113	-122.000	On fault midpoint, along strike
2	Wood	38.113	-122.114	10 km west of fault, at midpoint
3	RC	38.113	-122.570	50 km west of fault, at midpoint
4	RC	38.000	-122.000	South end of fault
5	Steel	37.910	-122.000	10 km south of fault, along strike
6	Wood	38.225	-122.000	North end of fault
7	Steel	38.113	-121.886	10 km east of fault, at midpoint

Table 4.75 – Asset sites and taxonomies for the multiple-asset test cases

4.5 Event-Based Risk Calculator

The tests for the event-based risk calculator assume the correct computation of the ground motion fields at the locations of the assets in the exposure model. Thus, the risk tests implicitly rely on the acceptance tests for the event-based hazard calculator.

The source model used for the tests comprises a single vertical strike-slip fault with a Gutenberg-Richter b-value equal to 0.9 and a slip rate of 2 mm/yr. The MFD is a Gutenberg-Richter distribution truncated between magnitudes 5.0 and 6.5, while the Ground Motion Prediction Equation (GMPE) used is Sadigh et al. (1997), with sigma set to zero.

Details of the fault geometry are given below:

Fault type: Strike slip

Fault dip: 90°

Fault plane depths: 0–12 km

Fault coordinates:

South end: 38.0000°N, 122.0000°W

North end: 38.2248°N, 122.0000°W

The list of assets in the exposure model used for the multiple-asset test cases for the event-based risk calculator is given in Table 4.75. The complete collection of input models and job configuration files used in these test cases can be accessed here: https://github.com/gem/oq-risklib/tree/master/openquake/qa_tests_data/event_based_risk

4.5.1 Single asset tests

The single asset test cases are designed to test the basic elements of the event-based risk calculator, such as:

- asset event loss table computation
- asset loss ratio exceedance curve computation
- asset loss exceedance curve computation

The location and taxonomy of the single asset in the exposure model used for the single-asset test cases for the event-based risk calculator are given in Table 4.1.

4.5.2 Multiple asset tests

The multiple asset test cases are designed to test the loss aggregation functions of the event-based risk calculator, such as:

- portfolio loss computation for a given ground motion field
- calculation of portfolio loss exceedance curves

4.5.3 Calculation with logic-trees

4.5.4 Insurance tests

Part IV

Benchmark Tests



5. Comparing the Classical and Event-Based

6. Comparison with Other Softwares

Part V

Performance Tests

7. Demos

- 7.1** Scenario Risk Calculator
- 7.2** Classical Risk Calculator
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