SHARE

SEVENTH FRAMEWORK PROGRAMME

Grant Agreement no. 226967
Seismic Hazard Harmonization in Europe
Project Acronym: SHARE

SP 1-Cooperation

Collaborative project: Small or medium-scale focused research project

THEME 6: Environment

Call: ENV.2008.1.3.1.1 Development of a common methodology and tools to evaluate earthquake hazard in Europe

D6.8 – Validated *OpenSHA* engine

Due date of deliverable: 31.05.2011
Actual submission date: 31.05.2011

Start date of project: 2009-06-01 Duration: 36

Swiss Seismological Service, Eidgenössische Technische Hochschule (SED-ETHZ)
L. Danciu, D. Monelli and J. Woessner

Revision: 1

Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	x
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of contents

1 Introduction

Evaluating and validating the seismic hazard engine used for the computation of SHARE hazard results is a continuous process as in every software project. This document updates the description of the hazard engine in sequence with Deliverables D6.1 and D6.4 that outlined the specifications and the seismic hazard engine of the GEM1 prototype project.

This document shortly describes the development strategy, evaluation and validation procedures that are performed in a common development of the new software package OpenQuake (www.openquake.org) and provides a description of the test cases and the results for the selected tests.

The validation of the OpenQuake engine mainly developed within the Global Earthqauke Model (GEM) project remains an ongoing task. The collaboration between SHARE and GEM scientists and IT-experts targets to meet the requirements of SHARE timely. As not all of the requirements, e.g. those of the final logic tree, were possible to be outlined at an early stage, the validation process will continue during the remaining period of the SHARE project to ensure the appropriate implementation of the hazard model philosophy.

2 OpenQuake – A short summary

The Seismic Hazard Engine (SHE-GEM1) prototype was replaced with the software package - OpenQuake. OpenQuake is available online (www.openquake.org) and the first stable version (v0.2) was released on January 3rd 2011. The next stable version (v0.4) is scheduled for June 2011. OpenQuake can be installed following the instructions presented at https://github.com/gem/openquake/wiki/Installation.

The hazard core of OpenQuake is based on a light version of OpenSHA, refactored to improve efficiency and maintainability. The refactoring process did not affect the main functionality and/or features of the initial OpenSHA. The resulted *OpenSHA-lite* was embedded in the OpenQuake engine following the test-driven development (TDD) techniques (Beck, 2003). TDD process implies a repetition of a short development cycle (see Figure 1-1): write failing automated test that defines a new functionality, then write code to pass the test, run the automated test and seen it succeed, then refactor the new code, and then repeat.

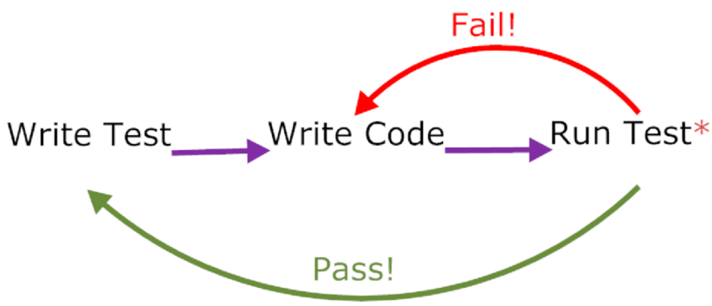


Figure 2-1 Graphical representation of the Test Driven Development (TDD) cycle

In the TDD framework, the verification of the *OpenSHA-lite* implies writing Java unit tests (JUnit) and defining test cases (components) to be evaluated. The following test cases were to this date defined:

1. Verification of hazard results computed for an area source zone
2. Verification of hazard results computed for a fault source zone
3. Verification of the implementation of Ground Motion Prediction Equations (GMPEs)

The first two test cases are the implementation of one set of test cases recommended by Pacific Earthquake Engineering Research (PEER) initiative to test and verify the numerical approaches and software used for hazard estimation (Thomas et al., 2010). The third test case is a validation procedure to assure that the ground motion prediction equations were correctly implemented. It is worth mentioning that the original OpenSHA was validated and found to be qualified through the PEER evaluation process; moreover the engine was also evaluated during the initial phase of GEM project (Danciu et al., 2010), thus the components of the OpenQuake engine have undergone an extensive testing phase.

3 OpenQuake – Results of testing software components

Technically, the JUnits are organized in two packages, first containing the PEER tests (Thomas et al., 2010) to evaluate earthquake rupture computation and the second package contains a suite of tests for the GMPEs. These packages are consistent with the hierarchical structure of the *OpenSHA-lite* and they are located under the Java tests package.

3.1 PEER Tests

The PEER tests are standard exercises aimed to be a reference for testing the current and future developed Probabilistic Seismic Hazard Assessment (PSHA) software packages. Two sets of exercises were proposed to evaluate the elements of any PSHA computational packages:

- A first set of test cases can be used to test the basic elements of the software, including
  - (i) How area and fault sources are modeled,
  - (ii) How finite ruptures are modeled,
  - (iii) How recurrence models are used, and
  - (iv) How the ground motion truncation is used in the calculation;

- A second set of exercises can be used to verify more complex elements of the software such as
  - (i) Modeling of subduction faults,
  - (ii) Treatment of multiple sources,
  - (iii) Use of different recurrence models,
  - (iv) Implementation of logic trees,
  - (v) Computation of different fractiles, and
  - (vi) Disaggregation.

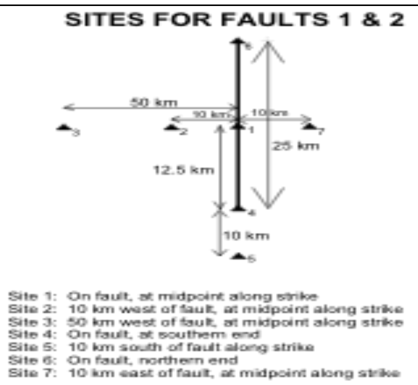
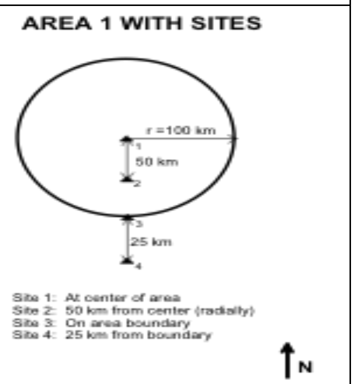
To validate the OpenQuake hazard engine there are up to date two exercises implemented as JUnits:

- *Test Case Set 1 – case 5* - exercise to test one Magnitude Frequency Distribution (MFD), specifically the truncated exponential model (defined by M_{min} = 5.0 and M_{max} = 6.5) and the computation of hazard from a fault source. The hazard is calculated for seven sites and there is no truncation of the ground motion distribution (sigma = 0.00).
- *Test Case Set 1 – case 10* – exercise to test the computation of hazard for an area source zone. Hazard calculation was performed for four sites, using the truncated exponential model (defined by M_{min} = 5.0 and M_{max} = 6.5). Area source is modeled as uniformly distributed point sources evenly discretize every 1km grid space at a fixed depth of 15km. No truncation of the ground motion distribution is considered. Both exercises consider the GMPE proposed by Sadigh et al [1997] and the local site geology fixed to “rock” for all investigated sites.

A summary of these exercises is presented in Table 3-1. Detailed descriptions of these test sets can be found on the PEER report, section 3 (Thomas et al 2010).

The validation procedure of the results is straightforward. The analytical solutions proposed by the PEER standard exercises were implemented into the JUnit classes and when the test is performed, the results of OpenQuake are compared within a tolerance level of 0.001.

The results of the *Test Case Set 1 – Case 5* are presented in Figure 3-2; whereas the results of the *Test Case Set 1 – Case 10* are presented in Figure 3-3. From these graphs it can be observed that there are no discrepancies between the analytical and OpenQuake results in the case of *Test Case Set 1 – Case 5*. There is a slightly small difference on the compared values for the *Test Case Set 1 – Case 10,* but the values are within the tolerance level fixed for the testing procedure.

<table>
<tr><td></td><td colspan="2">Test Cases Set 1</td></tr>
<tr><td rowspan="2">Geometry/Calculation Sites</td><td>Case 5</td><td>Case 10</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Description</td><td>Truncated
Exponential Model</td><td>Area Source with fixed
depth of 5km</td></tr>
<tr><td>Sites Coordinates</td><td>

Site	Latitude	Longitude
1	38.113	-122.000
2	38.113	-122.114
3	38.111	-122.570
4	38.000	-122.000
5	37.910	-122.000
6	38.225	-122.000
7	38.113	-121.886

</td><td>

Site	Latitude	Longitude
1	38.000	-122.000
2	37.550	-122.000
3	37.099	-122.000
4	36.874	-122.000

</td></tr>
<tr><td>b-val</td><td colspan="2">0.9</td></tr>
<tr><td>M_{min}</td><td colspan="2">5.0</td></tr>
<tr><td>M_{max}</td><td colspan="2">6.5</td></tr>
<tr><td>GMPE</td><td colspan="2">Sadigh et al (1997)</td></tr>
<tr><td>$sigma_{GMPE}$</td><td colspan="2">0</td></tr>
<tr><td>Site Geological Info</td><td colspan="2">Rock</td></tr>
<tr><td>Magnitude Scaling Relationships</td><td>$\log(A) = M - 4, \quad \sigma = 0$
$\log(W) = 0.5 * M - 2.15, \quad \sigma_w = 0$
$\log(L) = 0.5 * M - 1.85, \quad \sigma_L = 0$</td><td>Use 1 km grid spacing of point sources or small faults to simulate uniform distribution.</td></tr>
</table>

Table 3-1 Summary of the implemented test cases

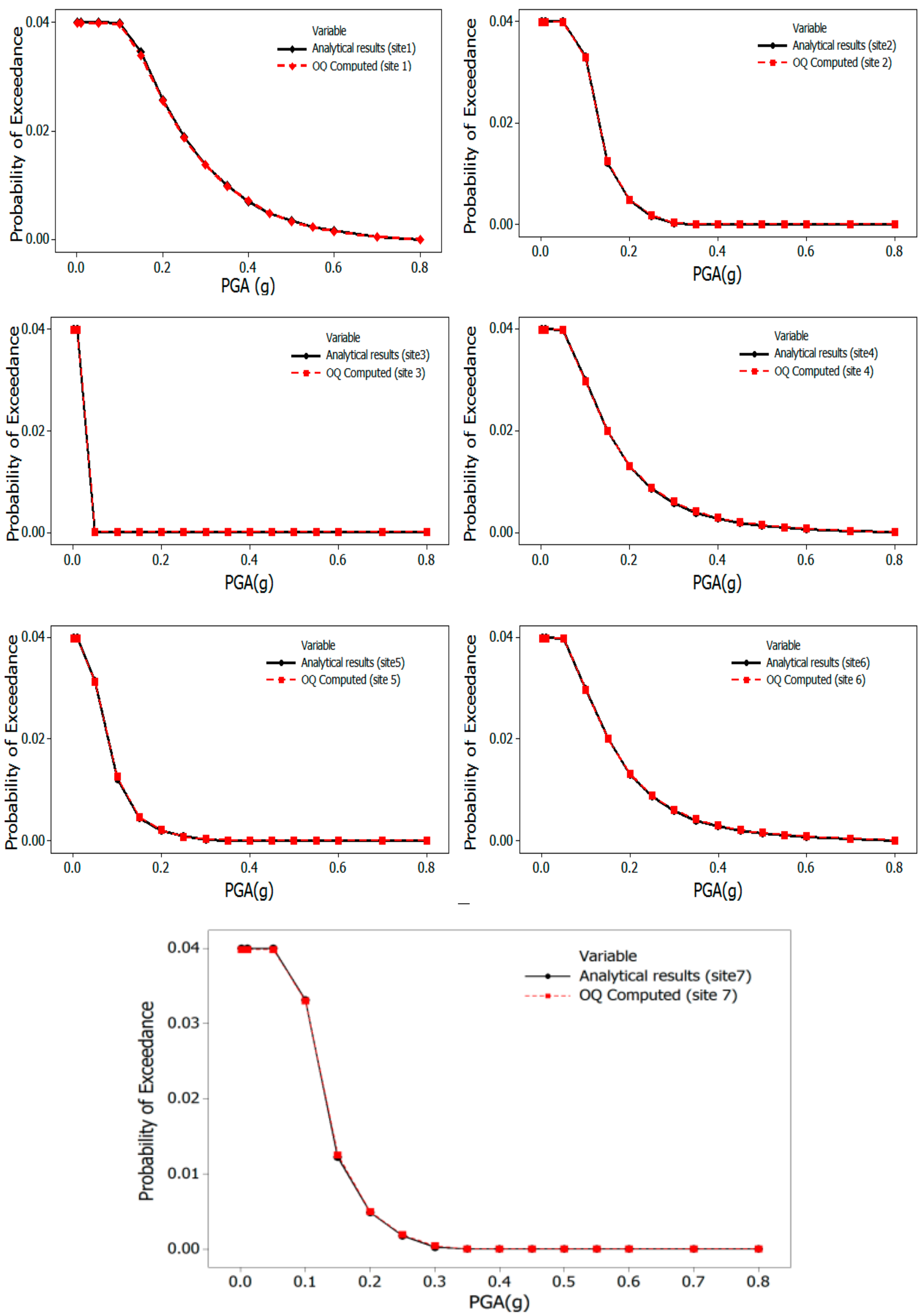


Table 3-2 Seismic Hazard Curves for seven sites defined in Test Case Set 1 – Case 5

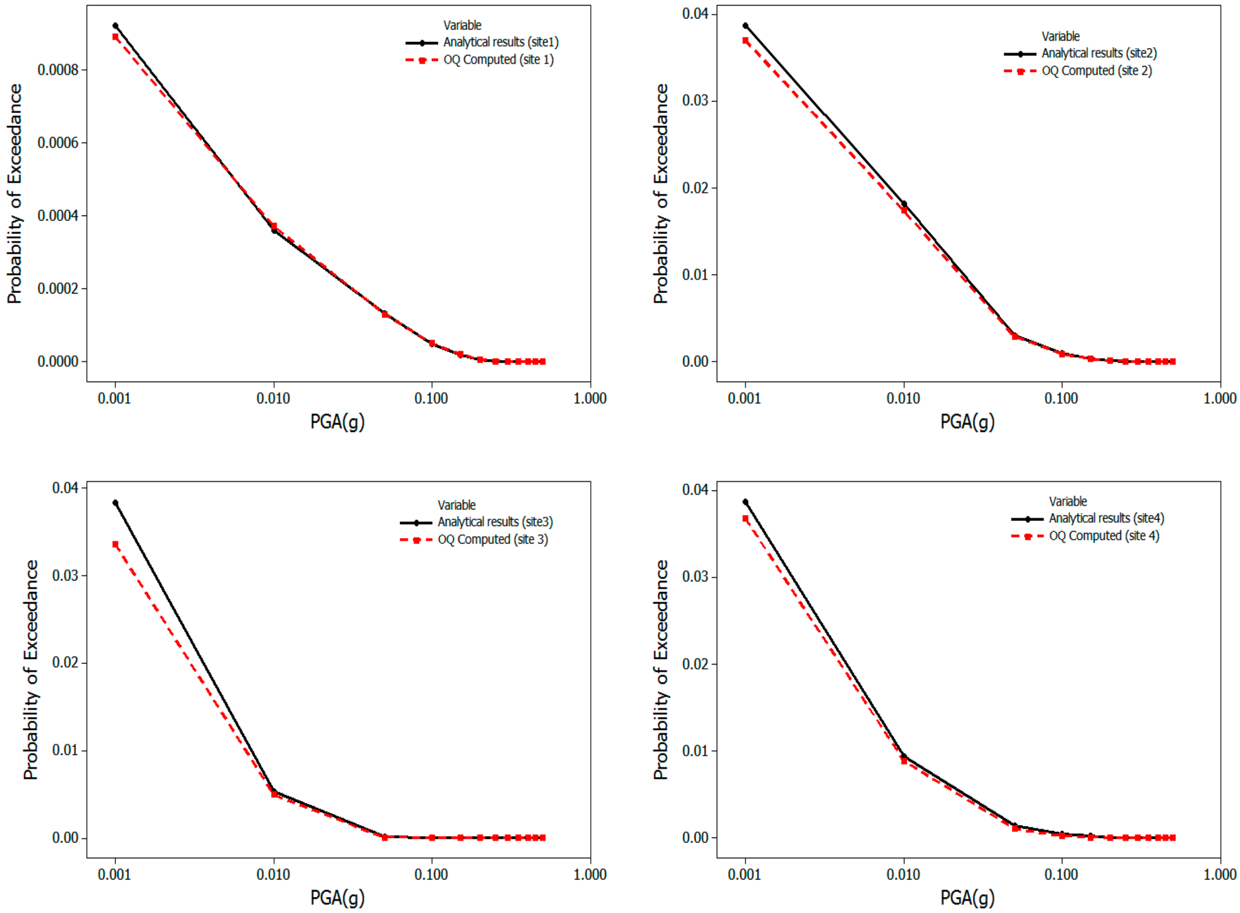


Table 3-3 Seismic Hazard Curves for four sites defined in Test Case Set 1 – Case 10

3.2 Ground Motion Prediction Equation - Validation

The GMPE validation is crucial due to their impact on the final hazard results. The GMPEs are add-ons to the computational core and they need to be validated individually. GMPEs validation follows the same pathway as presented for the validation of seismic sources.

Briefly, the validation procedure involves the implementation of GMPEs as Java classes according to the programming framework adopted in OpenQuake. After the implementation of the main GMPE classes, JUnit classes were written to validate the output/results. The validation consists on comparing the results of the GMPE - Java classes with the results submitted by experts or GMPEs authors. The comparison tables were produced for all possible combination of coefficients and they are specific to each GMPE. A tolerance level was arbitrarily fixed to 0.0001 and the JUnits fails if the difference between the expected and computed values is above this tolerance level. All GMPEs specified in deliverable D4.2 were implemented in the SHE-GEM1 prototype, and following the procedure described in Deliverable 6.4, they are under the review process to be merged into OpenQuake. So far, the OpenQuake was updated with the following GMPEs:

- Active shallow crustal regions: Akkar and Boomer [2010], Cauzzi and Faccioli [2008]

- Subduction Zones: Atkinson and Boore [2003], Lin and Lee [2008]

For the above ground motion models a number of tables of values were generated, 15 tables for Akkar and Boomer [2010]; 13 tables for Cauzzi and Faccioli [2008], 4 tables for Atkinson and Boore [2003] and 8 tables for Lin and Lee [2008]. Each table contains ground motion estimates for combinations of magnitude and distance bins, reported as function of focal mechanisms and different types of soil classifications. The table format was fixed to the following configuration:

- First column represents the moment magnitude evenly sampled within the magnitude validity range specified in the GMPE
- Second column represents the distance measure as specified in each GMPE; evenly sampled within the distance validity range
- The following columns contain ground motion values computed for the magnitude-distance bin, such as PGA, PGV and Spectral accelerations at exact the same spectral periods as specified in the ground motion model.

Plots of the validation results are presented in Figure 3-1 displaying the comparison of the results delivered from the experts (GMPE authors) in black and results from the values of the OpenQuake Java classes. All examples presented show agreement within the defined tolerance level.

3.3 Future validation efforts and tasks

As indicated in the introduction, evaluation and validation of a software project is an ongoing task until a final software release. Thus, SHARE and GEM programmers and scientists continue to work on these issues. Further plans imply implementation of all PEER test cases (Thomas et al, 2010) that would lead to an extensive validation of the following elements:

- Implementation of fault sources,
- Implementation of finite ruptures,
- Implementation of recurrence models
- Implementation of ground motion truncation;
- Modeling of subduction faults,
- Treatment of multiple sources,
- Use of different recurrence models,
- Implementation of logic trees,
- Computation of different fractiles, and
- Disaggregation.

The process of implementing the remaining GMPEs into the OpenQuake will continue and the validation will follow the procedure described in this report. More specifically, the next focus is to complete the GMPE implementation for Stable Continental Regions, including the following models:

- Atkinson [2008],
- Campbell [2003],
- Toro [2002]

With these GMPEs implemented and validated, OpenQuake will contain all the GMPEs selected by WP4 experts to form the ground motion logic tree.

For SHARE it is essential to fully test all components that will be used and needed for its hazard model. Apart of these numerical validations, there are other exercises ongoing, such as: sensitivity analysis of the weight assigned to each GMPE in the final SHARE logic tree, sensitivity of different type of ruptures used in the case of an area source, depth distribution and style-of faulting for an area source, treatment of maximum magnitude, etc. The results of these exercises will be presented inside the next deliverable.

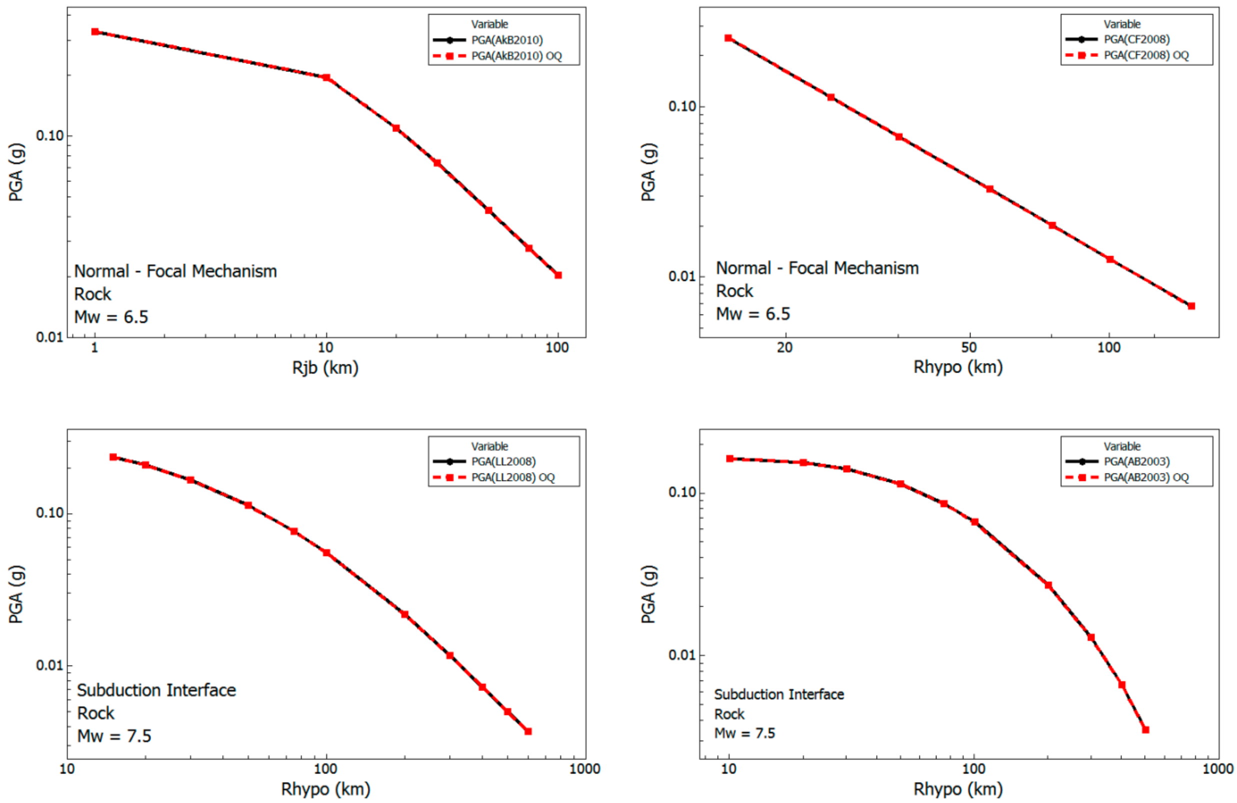


Figure 3-1 : GMPE validation plots for PGA; upper left plot for AkB2010, upper right plot for CF2008, lower left plot for LL2008 and lower right AB2003. Black lines show values obtained from GMPE authors, red dashed line shows values computed with the OpenQuake Java-classes.

4 REFERENCES

Document References

Atkinson, G. M., [2008] "Ground-motion prediction equations for eastern North America from a referenced empirical approach: Implications for epistemic uncertainty." *Bulletin of the Seismological Society of America,* Vol. 98 No.3, pp. 1304–1318.

Akkar, S. and Bommer, J. J., [2010] "Prediction of elastic displacement response spectra in Europe and the Middle East" *Earthquake Engineering and Structural Dynamics*, Vol. 36, No. 10, pp.1275–1301.

Atkinson, G.M. and Boore, D.M. [2003] "Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions." *Bulletin of the Seismological Society of America*, Vol. 93, No. 4, pp. 1703-1729.

Beck, K. (2003). Test-Driven Development by Example, Addison Wesley.

Campbell, K. W., [2003] "Prediction of Strong Ground Motion Using the Hybrid Empirical Method and Its Use in the Development of Ground-Motion (Attenuation) Relations in Eastern North America", Bulletin of the Seismological Society of America, Vol. 93, No. 3, pp. 1012–1033

Cauzzi, C., and Faccioli. E., [2008], "Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records". *Journal of Seismology*, Vol. 12, No. 4, pp. 453–475.

Danciu, L., Monelli, D., Pagani, M., and Wiemer, S. [2010] "GEM1Hazard: Review of PSHA software", GEM Technical Report 2010-2, GEM Foundation, Pavia, Italy.

Lin, P.-S., and Lee, C.-T. , [2008] "Ground-motion attenuation relationships for subduction-zone earthquakes in northeastern Taiwan." *Bulletin of the Seismological Society of America*, Vol. 98, no. 1, pp. 220–240

Sadigh, K., Chang, C.-Y., Egan, J. A., Makdisi, F., and Youngs, R. R. [1997] "Attenuation relationships for shallow crustal earthquakes based on California strong motion data." *Seismological Research Letters*, Vol. 68, No.1, 180–189

Thomas, P., Wong, I. and Abrahamson, N. (2010). Verification of Probabilitisc Seismic Hazard Analysis Computer Programs. Pacific Eearthquake Engineering Research Center (PEER), Berkley, College of Engineering, University of California.

Toro, G.R., N.A. Abrahamson and J.F. Schneider [1997] "Model of strong ground motions from earthquakes in central and eastern North America: best estimates and uncertainties" *Seismological Research Letters,* Vol. 68, pp. 41-57.

Toro G. R., [2002] Modification of the Toro et al. [1997] attenuation equations for large magnitudes and short distances. Risk Engineering, Boulder. Available online at: (www.riskeng.com/PDF/atten_**toro**_extended.pdf)

Website references

1. OpenQuake
[Available at http://www.openquake.org]
2. OpenQuake Source Repository
https://github.com/gem/openquake/wiki/Installation
3. JUnit Test
Resources for Test Driven Development
[Available at http://www.junit.org]