GLOBAL EARTHQUAKE MODEL
working together to assess risk

PSHA input model documentation for Continental Southeast Asia (SEA)

GEM Hazard Team

Version history

Table 1 summarises version history for the SEA input model, named according to the versioning system described here, and indicating which version was used in each of the global maps produced since 2018. Refer to the GEM Products Page for information on which model versions are available for various use cases. The changelog describes the changes between consecutive versions and are additive for all versions with the same model year.

***Table 1** – Version history for the SEA input model.*

Version	2018.1	2019.1	2022.1	2023.1	Changelog
v2018.0.0	X				First version of the model.
v2018.0.1		X			Corrected source model: some gridded seismicity sources were missing in West Malaysia and epistemic uncertainty was not being applied correctly to one source.
v2018.0.2			X		Removed the fake source 287716burma that was used to force the logic tree to work in former versions of the OpenQuake Engine. Results are unchanged.
v2018.1.0				X	Mmin extended to M4 for crustal distributed seismicity. Source ids were revised to work with disaggregation by source. Inslab source files were consolidated into a single one. gmmLT.xml updated with more recent GMPEs. A few fault sources that violated ordering conventions in their trace coordinates were corrected. Removed point sources with a-values close to -99 (no change to hazard).

The following text describes v2018.1.0.

Authors: C.-H. Chan, T. Ornthammarath

For any additional information about this model please contact:
chchan@ntu.edu.sg and teraphan.orn@mahidol.edu

1 Summary

The seismic hazard model for Continental Southeast Asia (SEA) covers Myanmar, Thailand, Vietnam, Laos, Cambodia, Singapore, and West Malaysia. The model was developed by a group of scientists from Singapore, Thailand, Myanmar and Vietnam. Two seismic source models were independently developed by Chan et al. (2017) and Ornthammarath et al. (2020). The source model of Chan et al. (2017) covers a region that is larger than the extent of the SEA model used in the global mosaic, with sources extending east to Papua New Guinea and south to Indonesia, while the source model of Ornthammarath et al. (2020) covers the same extent of the SEA model used in the global mosaic. Both source models are included in the final SEA model by using a source model logic tree, where the models are assigned equal weights. The Ground Motion Characterisation for the two models is the same. The ground motion logic tree contains ground motion prediction equations for active shallow crust and, subduction interface and intraslab. The SEA model was originally created for the OpenQuake (OQ) engine. Previous studies in the region include Petersen et al., 2004.

2 Tectonic overview

Southeast Asia lies at the confluence of several plate boundary systems. The study area itself lies on the Sunda Plate, which is separated from greater Eurasia by a system of strike-slip faults, primarily the sinistral Xianshuehe- Red River Fault and a conjugate set of distributed right-lateral faults near the Chinese border with northern Vietnam, Cambodia, Myanmar and Laos. The plate is then bound on its northwestern margin by the right-lateral Sagaing Fault, which separates it from India. The Sagaing Fault is a north-striking transform boundary between the Sunda Plate and the Indo-Australian Plate or plates (depending on the definition) which becomes increasingly more convergent to the south into Indonesia as the boundary wraps around to the southeast; here it becomes primarily a subduction zone off of Sumatra and Java, though Sagaing-type deformation continues into Sumatra as the Great Sumatran Fault. The eastern margin of the Sunda plate is composed of a complicated set of plate boundaries that are primarily subduction zones between microplates and mobile belts in the Philippines south through Sulawesi and into Papua; these produce very frequent moderate to large magnitude earthquakes but are distant enough from the Indochina mainland to pose somewhat muted hazard. Relatively slowly-slipping active faults are distributed throughout the interior of the Sunda Plate, but these also produce smaller and less frequent earthquakes than the major plate boundaries described above.

3 Basic Datasets

The two models utilise a recently compiled set of shallow active faults.

See Chan et al. (in prep) and Ornthammarath et al. (in prep) for descriptions of the datasets used for developing the hazard model.

4 Hazard Model

4.1 Seismic Source Characterisation

The seismic source characterisation (SSC) is the combination of two seismic source models (SSM) independently developed by Chan et al. (in prep) and Ornthammarath et al. (in prep), which are hereinafter referred to as SSM1 and SSM2, respectively. Both SSMs consists of various seismic source typologies to describe earthquake occurrence in different tectonic settings. Distributed seismicity is used to model both active shallow and deep intraslab seismicity, while fault sources are used to model seismicity occurring on shallow crustal faults and large subduction interface events.

The OQ implementation for SSM1 uses four source typologies (two in OQ). The shallow background and intraslab seismicity are modelled using **Area Sources**, while crustal faults and subduction interface faults are modelled using **Simple Fault Sources**. The OQ implementation for SSM2 uses four OQ source typologies. The background seismicity for active shallow crust is modelled using **Point Sources** with spatially variable properties. Deep intraslab seismicity is also modelled using **Point Sources**. Crustal faults are modelled using **Simple Fault Sources**, and **Characteristic Fault Sources** (with simple fault geometry). Subduction faults are modelled using **Complex Fault Sources**. The OQ sources are depicted in the

Epistemic Uncertainties Epistemic uncertainties are described using a logic tree. This permits the use of both SSMs, each represented by one branch. SSM1 and SSM2 are assigned equal weights of 0.5. Additionally, SSM2 also includes epistemic uncertainty of the maximum magnitude modelled on the Burma Sumatra Megathrust.

4.2 Ground Motion Characterisation

Table **??** shows the ground motion logic tree for SEA. The logic tree is the same for SSM1 and SSM2, and distinguishes between five main tectonic regions. Only three are within the extent of the SEA model used in the global mosaic, and they are: *Active Shallow Crust*, *Subduction Interface*, and *Subduction IntraSlab*.

Epistemic Uncertainties For every tectonic region, epistemic uncertainty is considered by using multiple GMPEs, each with an associated logic tree weight.

Subduction Interface	Weight
AtkinsonBoore2003SInterNSHMP2008	0.1
AbrahamsonEtAl2015SInter	0.45
ZhaoEtAl2006SInterNSHMP2008	0.45
Active Shallow Crust	**Weight**
ZhaoEtAl2006Asc	0.33
BooreEtAl2014	0.33
ChiouYoungs2014	0.34
Philippine Subduction	**Weight**
ClimentEtAl1994	1.0
Subduction IntraSlab	**Weight**
AtkinsonBoore2003SSlabNSHMP2008	0.33
ZhaoEtAl2006SSlab	0.34
AbrahamsonEtAl2015SSlab	0.33
Philippine Active Shallow Crust	**Weight**
AkkarCagnan2010	1.0

Table 2 *– GMPEs used in the SEA model.*

5 Results

Hazard curves were computed with the OQ engine for the following:

- Intensity measure types (IMTs): peak ground acceleration (PGA) and spectral acceleration (SA) at 0.2s, 0.3s, 0.6s, 1.0s, and 2s
- reference site conditions with shear wave velocity in the upper 30 meters (Vs30) of 760-800 m/s, as well as for Vs30 derived from a topography proxy (Allen and Wald, 2009)

Hazard maps were generated for each reference site condition-IMT pair for 10% and 2% probabilities of exceedance (POEs) in 50 yrs. Additionally, disaggregation by magnitude, distance, and epsilon was computed for the following cities: Kuala Lumpur, Vientiane, Bangkok, Phnom Penh, Singapore, Hanoi and Yangon. The results were produced as csv files and bar plots for each of the following combinations:

- hazard levels for 10% and 2% POE in 50 yrs
- PGA and SA at 0.2s, 0.3s, 0.6s, and 1.0s
- Vs30=800 m/s

All calculations used a ground motion sigma truncation of 5. Results were computed for sites with 6 km spacing

Visit the GEM Interactive Viewer to explore the Global Seismic Hazard Map values (PGA for Vs30=800 m/s, 10% poe in 50 years). For a comprehensive set of hazard and risk results, see the GEM Products Page.

6 References

Allen, T. I., and Wald, D. J., 2009, On the use of high-resolution topographic data as a proxy for seismic site conditions $Vs30$, Bulletin of the Seismological Society of America, 99, no. 2A, 935-943

Chan C.-H-, Wang Y., Shi X., Ornthammarath T., Warnitchai P., Kosuwan S., Thant M., Nguyen P.H., Nguyen L. M., Solidum Jr. R., Irsyam M., Hidayati S., Sieh K. (2017). Toward uniform probabilistic seismic hazard assessments for Southeast Asia. 2017 AGU Fall Meeting Abstract #238207.

Ornthammarath T, Warnitchai P, Chan C-H, Wang Y, Shi X, Nguyen PH, Nguyen JM, Kosuwan Sand Thant M (2020). Probabilistic Seismic hazard assessments for Northern Southeast Asia (Indochina): Smooth seismicity approach. Earthquake Spectra 36(S1): 69–90.

Petersen, M.D., Dewey, J., Hartzell, S., Mueller, C., Harmsen, S., Frankel, A.D., and Rukstales, K., 2004, Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the southern Malaysian Peninsula: Tectonophysics, v. 390, p. 141–158.

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If you have any questions please contact the GEM Foundation Hazard Team at: hazard@globalquakemodel.org