Modelling Subduction Zone Seismogenic Hazards in Southeast Asia for Seismic Hazard Assessments

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Abstract

A three-dimensional subduction zone seismic source model for the Asia-Pacific region (ASIA-1) has been developed for use in seismic hazard assessments of large engineered structures. Subduction zones are of great importance globally as they are highly seismically active plate boundaries and produce mega earthquakes.

A seismic source model has been developed incorporating shallow crustal sources and complex deep sources covering the subduction interface and intraslab. The model, with over 200 crustal surface zones and 120 subduction source zones, covers as far as Iran in the Near East, as far as Mongolia in northern Asia, most of Southeast Asia as well as the Pacific Islands of New Caledonia, Fiji and Tonga.

A novel approach to the ASIA-1 model is the segmentation of the upper zones of the subduction plate into an outer rise, prism and shallow crustal zones to model the differing structural components as the plate subducts.

The Andaman-Arakan and Sunda-Java Trenches as viewed in 3D gives a clearer understanding of relationships between subducting and over-riding plates, whilst convergence of the Sunda and Philippine Plates have a more complex relationship. The subduction zone separating the Indo-Australian with the Eurasian and Pacific Plates is the focal point of the ASIA-1 subduction zone model that has been mapped and included in many of our international PSHA studies. Other subduction zones, including the Philippines Mobile Zone, New Britain, New Hebrides and Kermadec-Tonga Trenches are also modelled.

Improved understanding of the complex relationships at plate boundaries is fundamental to developing appropriate seismic hazard assessments.

Keywords: seismotectonics, seismic hazard, PSHA, subduction zone, Southeast Asia

1. INTRODUCTION:

Probabilistic Seismic Hazard Assessments (PSHA) are conducted for large, engineered structures such as dams, mine sites, offshore plants and onshore LNG facilities. The fundamental component in conducting such PSHA studies is in quantifying hazard as realistically as possible within nature. Along complex plate boundaries the intrinsic tectonic plate motions and stress release producing seismicity are critical aspects in quantifying these along the subduction as intraslab and interface events. The ASIA-1 seismotectonic model captures both background seismicity and that relating to large faults and subduction processes. This paper focuses on modelling aspects of the intraslab defined by variations in depth and the extended interface where large earthquakes are produced.

2. SEISMOTECTONIC MODEL:

2.1 Crustal Areas of ASIA-1 Seismotectonic Model:

The ASIA-1 seismotectonic model is composed of uniform seismicity area zones covering Southeast Asia and beyond, including as far west to the Himalayas, northwards to western and southern China, eastwards to the Philippines and Papua New Guinea and southwards to Indonesia (see Figure 1). This model seamlessly merges with the DIM-AUS seismotectonic model to the south on the boundary between the Sunda and Australian Plates (Dimas & Venkatesan, 2016). Zone boundaries have been defined using geology, tectonics and structural units relating these to the seismicity. The level of detail used to delineate the crustal portion of the
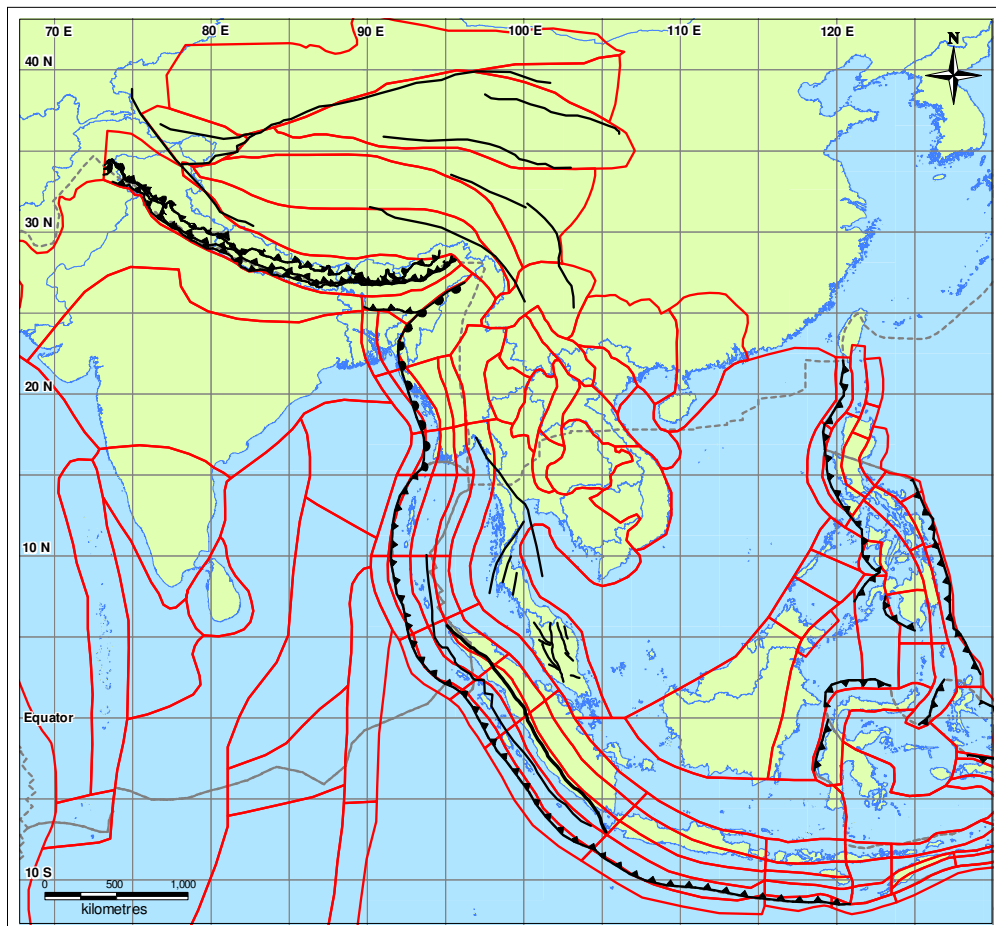

Figure 1: ASIA-1 seismotectonic source model

subduction zone is carefully constructed to delineate the two merging plates and the intricate seismic relations as one plate subducts down beneath the other, causing varying seismic effects in the crustal layer of the other plate.

In Figure 2 (Banda Sea-Irian Java region) and Figure 3 (PNG region) close-up zone boundaries are shown with particular difference being given to the subduction zone complex. The red zones are crustal level area zones typically 2-20 or 2-35 kilometres depending on topography and tectonic relations. Apart from the crustal area sources, the ASIA-1 model also incorporates active trenches, major faults and any local faults prominent within the context of the plate motions within the upper layer of the crust. Input parameters, including activity rates, b-values, maximum magnitudes (Mmax) are currently being revised as additional seismic data is collected and processed for each source zone. The plate boundaries as defined by Bird (2002) are also shown as grey outlines, with the main trenches and faults marked as black features.
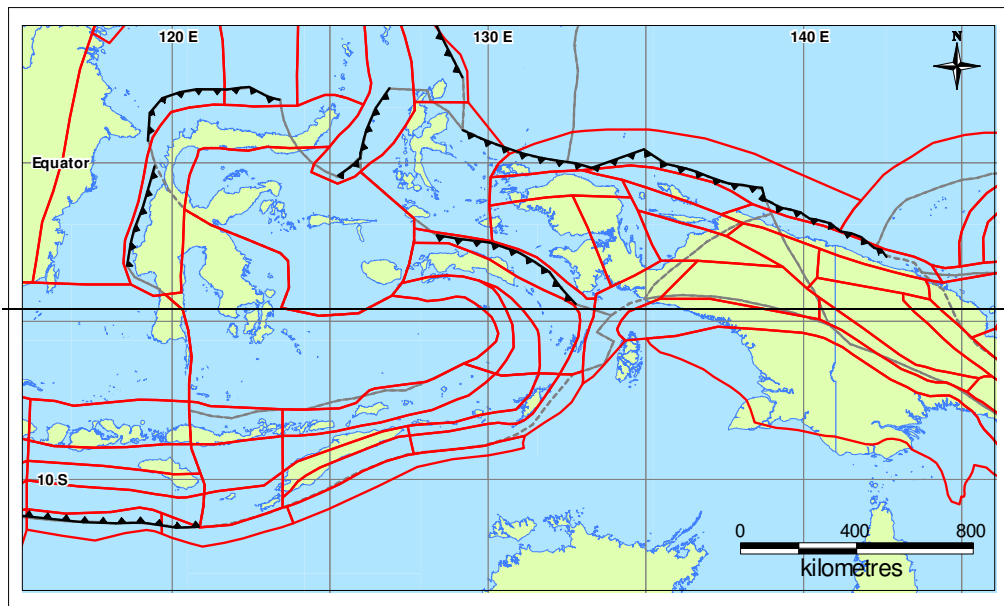

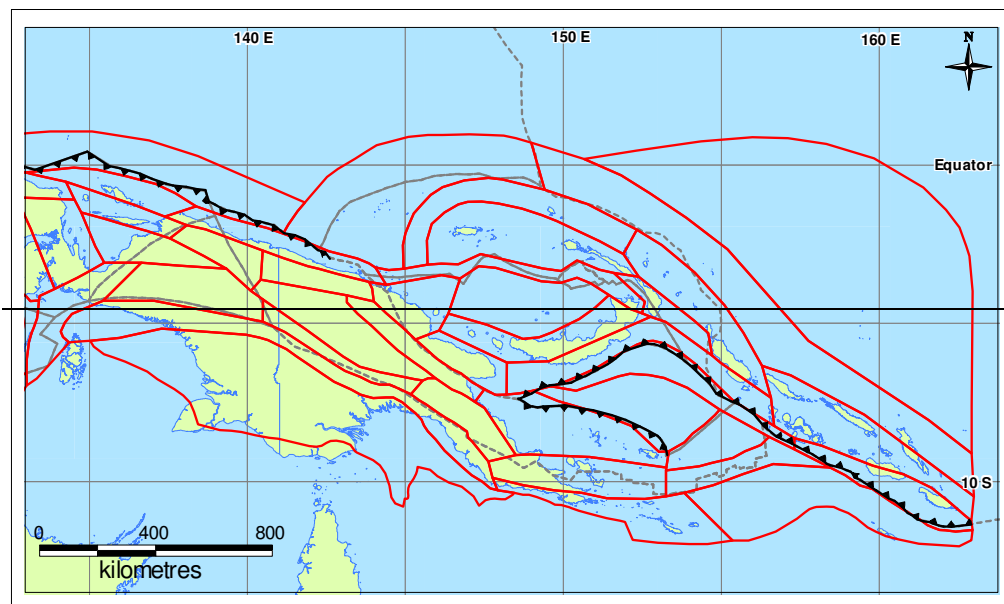**Figure 2: ASIA-1 model in Banda Sea-Irian Java region**

Figure 3: AISA1 model in PNG region

2.2 Intraslab Areas of ASIA-1 Seismotectonic Model:

Seismicity between the subducting and over-riding plates is shown in Figure 4 with a series of cross-sections marked crossing the trench at a perpendicular angle to the trench, with two examples given in Figure 5 showing the slab dip angle and differences in seismicity down-dip. This information has been assessed and quantified
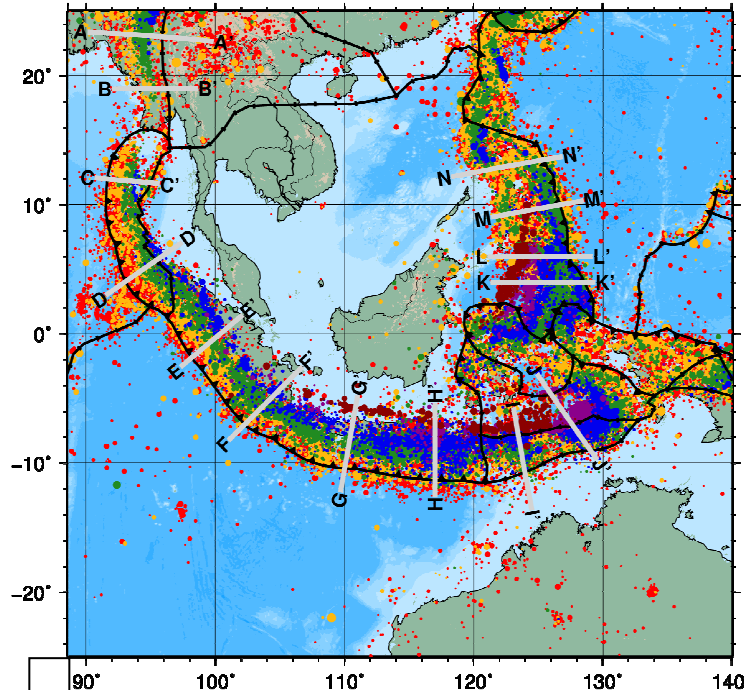

Figure 4: Seismicity along subduction zones colour according to depth (red=0-35km, gold=35-70km, green=70-150km, blue=150-300km, purple 300-500km, deep red=500-700km)
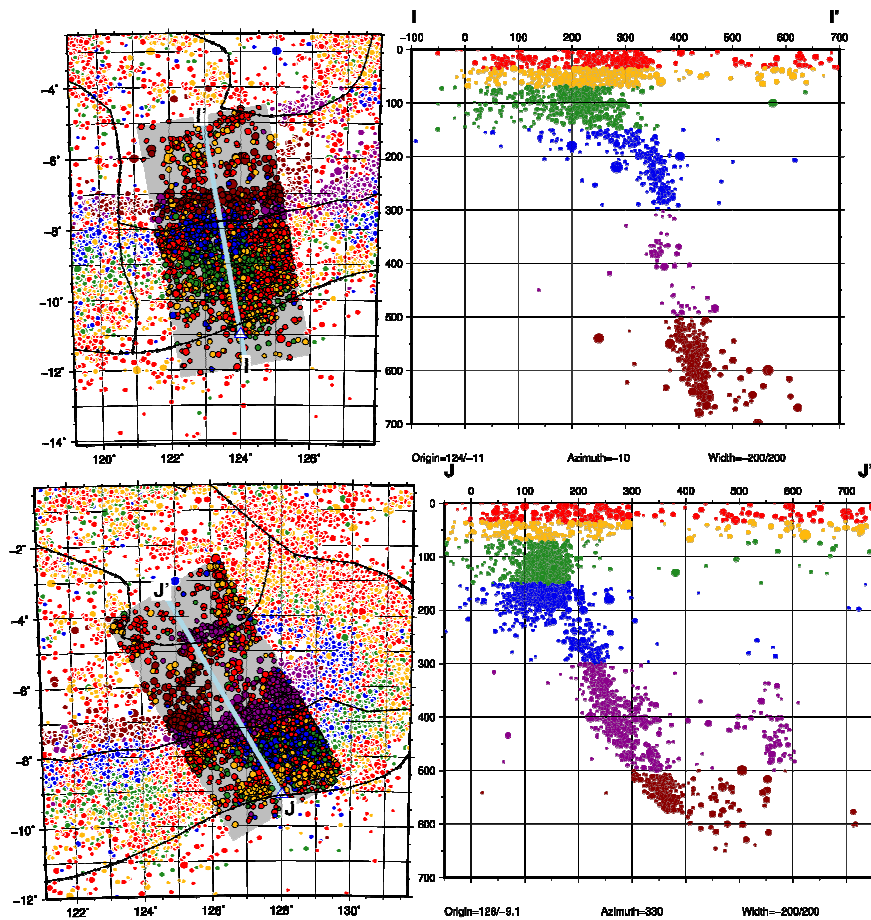

Figure 5: Examples of planar (left) & cross-section (right) images from Banda Sea region

for PSHA studies in the region. Earthquake magnitude recurrence parameters have been determined for each source zone down-dip the subducting plate, with lower activity rates and b-values identified in zones as seismicity deepens.

Unique approach to modelling the intraslab hazard is presented in a series of varying depth blocks, each assigned to changes in geological, chemical and physical properties of the Earth. The depth ranges include from upper to lower levels, a series of zones labelled with a letter unique to each depth range: E is assigned a depth range of 35 to 70 km; F is assigned a depth range of 70 to 150 km; G is assigned a depth range of 150 to 300 km; H is blank to represent the lack of seismicity between level G and I; I is assigned a depth range of 300 to 500 km; and J is assigned a depth range of 500 up to 700 or 900 km (in some instances). Note that the depth ranges of A, B, C and D are often summed into one upper crustal layer for depth ranges of 0 to 20 or 2 to 35 km.

2.3 Interface Subduction Seismotectonic Model:

The interface feature of the ASIA-1 seismotectonic model allows for the mega earthquakes to be modelled separately to those along the intraslab. The minimum and maximum magnitude of each source is typically limited to at least M8.0$^+$, thereby allowing only the mega events along the interface. However, the key difference to other seismotectonic models is that the depth range is sufficient to allow for the larger rupture areas to be accommodated by these events, hence 2 to 150 km depth range with a variable dip-angle depending on each individual feature when observed in 3-D.

Table 1: Sample parameters of ASIA-1 fault and interface sources (work to date)

Fault Source	Slip Rate (mm/yr)	Mmin-Mmax	b	Depth Range (km)	Dip Angle (º)
Arakan Trench (Interface)	13	8.2 – 8.8	1.00	0 – 60 – 150	25 – 55
Andaman Trench (Interface)	13	8.2 – 8.8	1.00	0 – 60 – 150	25 – 55
Sumatra Trench (Interface)	10 – 45	8.0 – 9.3	0.80	0 – 60 – 150	13 – 25
Mentawi Fault (Strike-slip crustal)	10	6.9 – 7.5	0.75	0 – 12	90 – 90
Nias-Bati Fault (Strike-slip crustal)	15	6.9 – 7.5	0.75	0 – 12	90 – 90
Sumatra Fault (Strike-slip crustal)	20	8.0 – 8.4	0.80	0 – 60 – 150	90 – 90
West Andaman Fault (Strike-slip crustal)	10	6.9 – 7.5	0.75	0 – 12	90 – 90
Zone Source	**Activity (N0)**	**Mmin-Mmax**	**b**	**Depth Range (km)**	**Depth Level**
CRUSTAL AREA ZONES					
Sumatra North Outer Rise	2,590	5.0 – 7.5	0.81	2 – 20	ABC
Sumatra North Prism	362,430	5.0 – 8.0	1.06	2 – 35	ABCD
Sumatra North Shallow Crustal	18,540	5.0 – 7.5	0.87	2 – 20	ABC
Sumatra North	8,560	5.0 – 7.5	0.83	2 – 20	ABC
Sumatra Central Outer Rise	37,230	5.0 – 7.5	1.00	2 – 20	ABC
Sumatra Central Prism	98,600	5.0 – 8.0	0.96	2 – 35	ABCD
Sumatra Central Shallow Crustal	11,310	5.0 – 7.5	0.87	2 – 20	ABC
Sumatra Central	990	5.0 – 7.5	0.85	2 – 20	ABC
INTRASLAB AREA ZONES					
Sumatra North E	119,040	5.0 – 7.0	0.91	35 – 70	E
Sumatra South E	1,294,900	5.0 – 7.0	1.05	35 – 70	E
Sumatra North F	490,820	5.0 – 7.0	1.10	70 – 150	F
Sumatra South F	490,820	5.0 – 7.0	1.03	70 – 150	F
Sumatra North G	51,975	5.0 – 7.0	0.98	150 – 300	G
Sumatra South G	252,840	5.0 – 7.0	1.15	150 – 300	G
N/A in Sumatra	N/A	N/A	N/A	300 – 500	I
N/A in Sumatra	N/A	N/A	N/A	500 – 700	J

4. CONCLUSION:

PSHA studies need to account for all identifiable sources within a region to account for seismicity in seismic hazard calculations. Along complex subduction zones, particularly as identified in south-east Asia, this becomes a process of collecting sufficient information to accurately account for the various fault, trench and background sources within a seismotectonic model.

The improved ASIA-1 seismotectonic model seamlessly merges with other models (e.g. DIM-AUS) to neighbouring plates of the Indo-Australian Plates. It also considers this boundary interaction in a manner that allows the subduction trench to be accommodated within the ASIA-1 seismotectonic model, utilising depth variation area sources together with the interface trench and other fault sources.

REFERENCES:

Allen, T.I. (2012) Stochastic ground-motion prediction equations for south-eastern Australian earthquakes using updated source and attenuation parameters. Record 2012/69, Geoscience Australia, Canberra.

AS 1170.4 (2007) Structural design actions. Part 4: earthquake actions in Australia. Standards Australia.

Bird, P. (2002) An updated digital model of plate boundaries. Department of Earth and Space Sciences, University of California, Los Angeles, CA, Geochemistry Geophysics Geosystems, 4(3), 1027, [doi:10.1029/2001GC000252].

Clark, D., McPherson, A. and Collins, C.D.N. (2011) Australia's seismogenic neotectonic record: a case for heterogeneous intraplate deformation. Record 2011/11. Geoscience Australia, Canberra.

Dimas, V-A. and Venkatesan, S. (2016) Seismotectonic model for the Australian Plate – Beyond Borders. Australian Earthquake Engineering Society, Conference Proceedings, November, Melbourne.

Gutenberg, B. and Richter, C.F. (1944) Frequency of Earthquakes in California. Bulletin of Seismological Society of America. 34, 185–188.

Gutenberg, B. and Richter, C.F. (1956) Magnitude and Energy of Earthquakes. Annali di Geofisica. 9, 1–15.

Liang, J.Z., Hao, H., Gaull, B.A. & Sinadinovski, C. (2008) Estimation of strong ground motions in southwest Western Australia with a combined Green's function and stochastic approach. Journal of Earthquake Engineering, 12, 382-405.

Shaw, R.D., Wellman, P., Gunn, P.J., Whitaker, A.J., Tarlowski, C. and Morse, M.P. (1996) Guide to using the Australian crustal elements map. Australian Geological Survey Organisation Record 1996/30.

Somerville, P., Graves, P., Collins, N., Song, S.G. & Ni, S. (2009) Source and ground motion models for Australian earthquakes. Australian Earthquake Engineering Society, Conference Proceedings, November, Newcastle.