The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

H4.SMR/1645-21

"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

Seismic Hazard Analysis "TRIGA 2000" Nuclear Site Bandung Indonesia

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IAEA/ICTP Workshop on
Earthquake Engineering for Nuclear Facilities – Uncertainties
In Seismic Hazard Assessment

Seismic Hazard Analysis "TRIGA 2000" Nuclear Site Bandung Indonesia

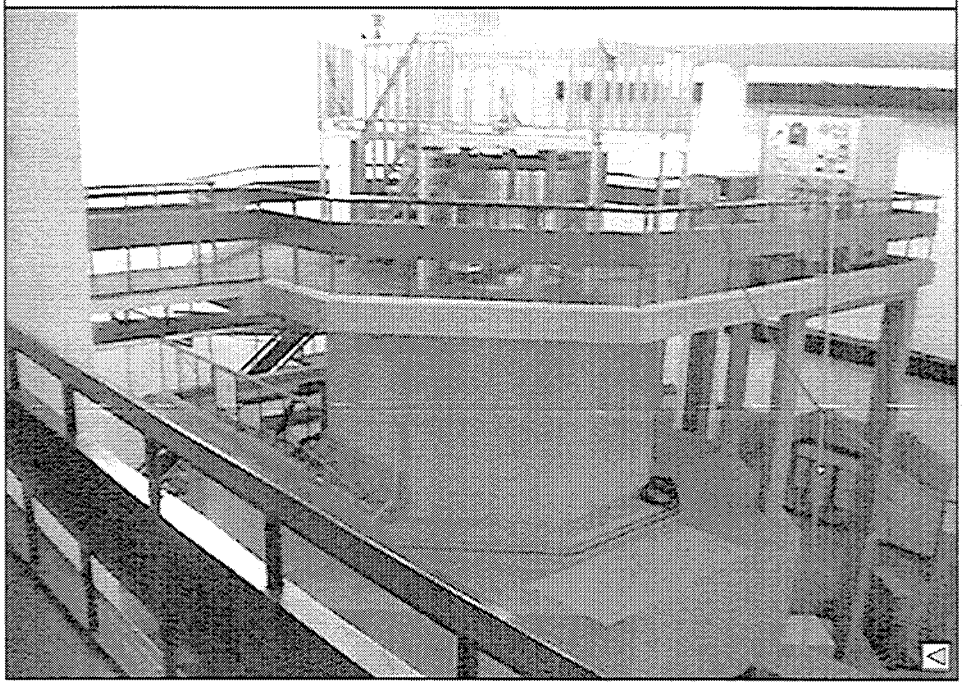
Trieste, Italy, 14 – 25 February 2005

Unit 32 – Rizkita Parithusta

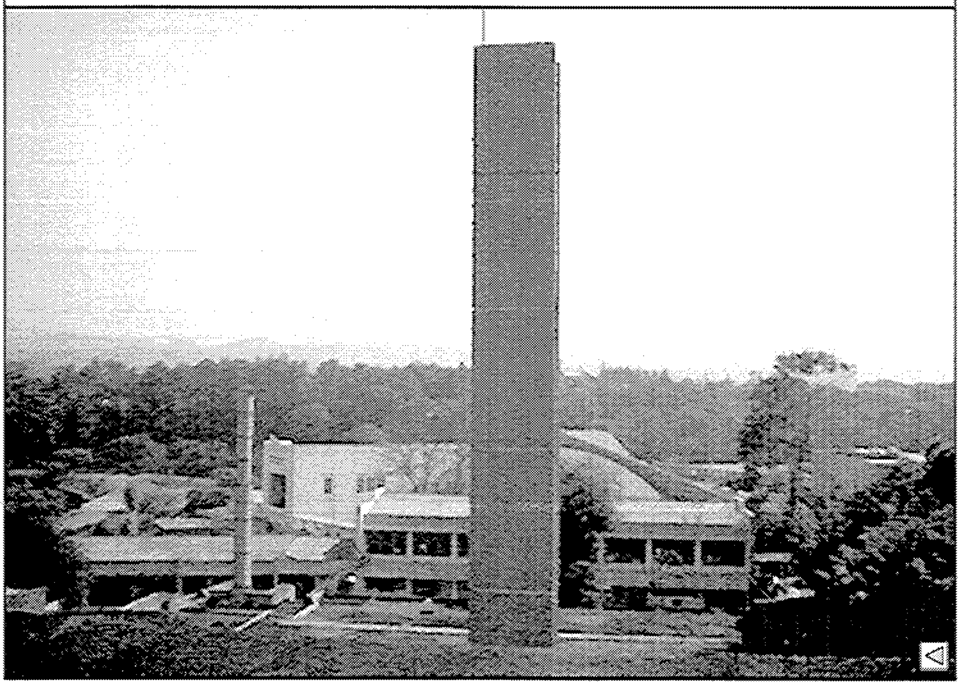
Content

- IAEA (International Atomic Energy Agency)' **Evaluation of Seismic Hazards for Nuclear Power Plants** Safety Standards Series No. NS-G-3.3 2002, Date of Issue: 21 March 2003
- Site Condition
- Geology
- Seismic Source Zone
- Seismicity Evaluation base on earthquake historical, geology and etc.
- Attenuation function
- Probability

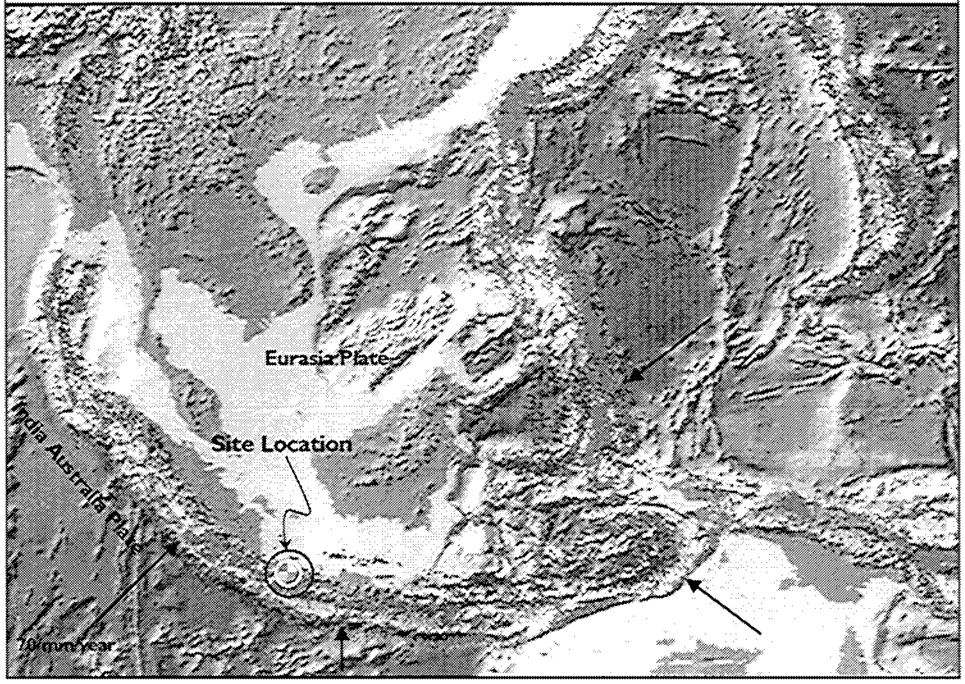
REACTOR ROOM

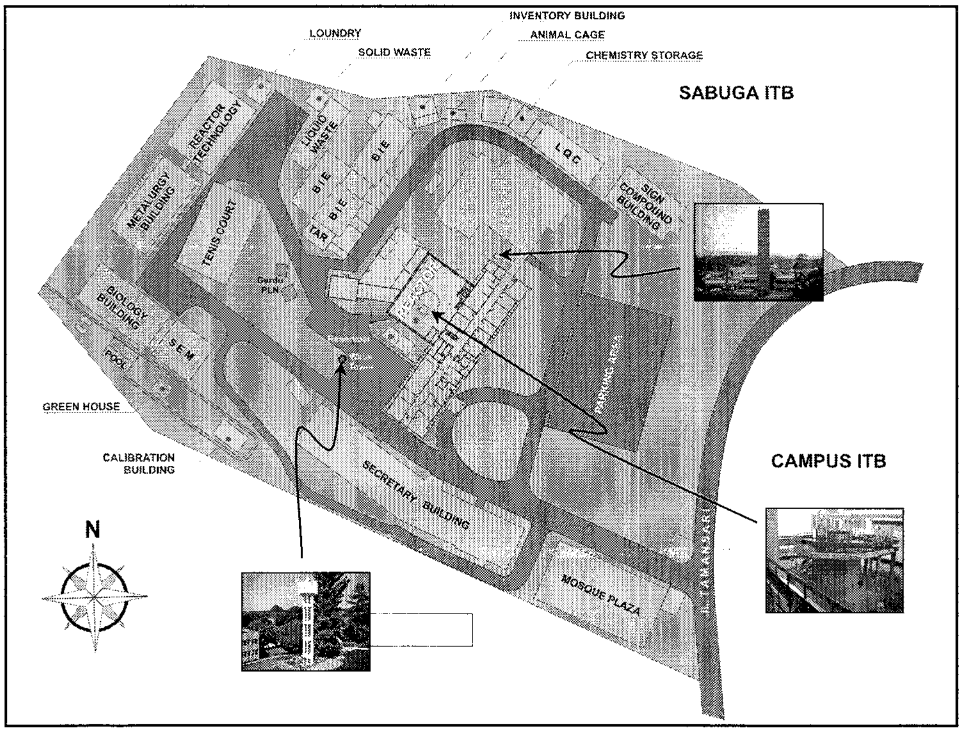


STACK

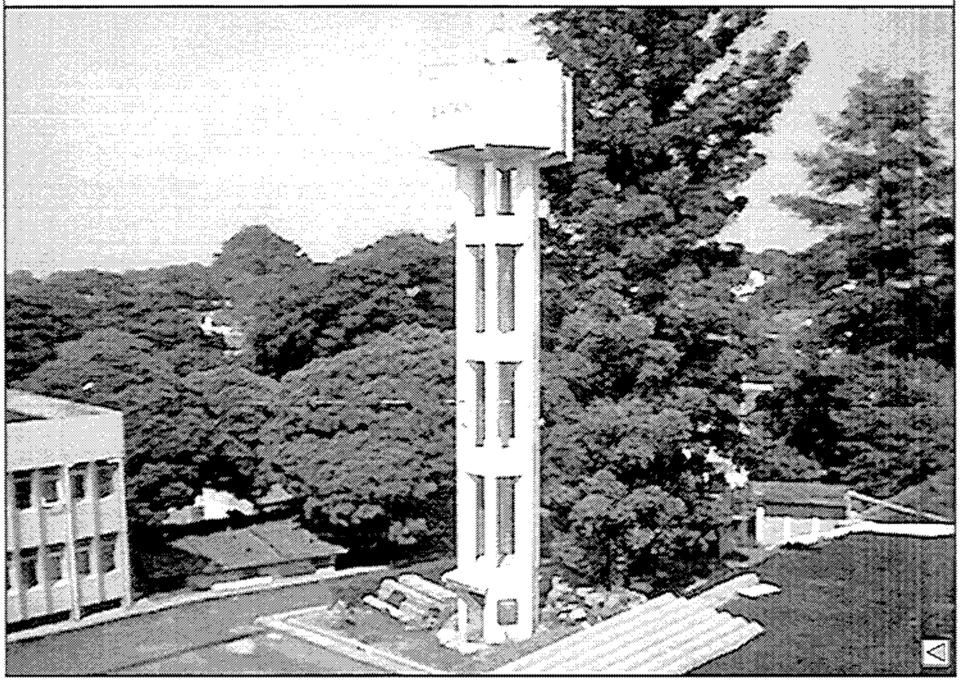


SEISMIC MAP OF INDONESIA





WATER TOWER



Introduction

TRIGA

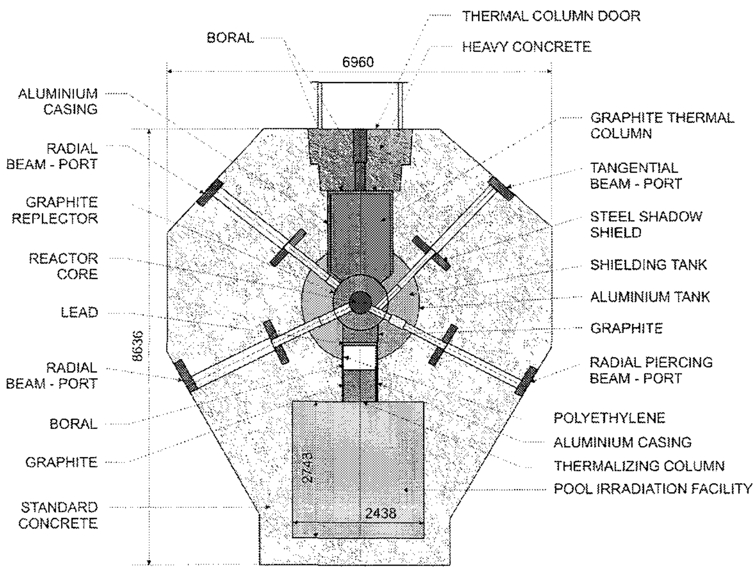
(**T**raining, **R**esearch and **Isotope** Production from **G**eneral **A**tomic)

- ✓ October 10th 1964 250 KW
- ✓ 1971 1000 KW
- ✓ April 1996 2000 KW

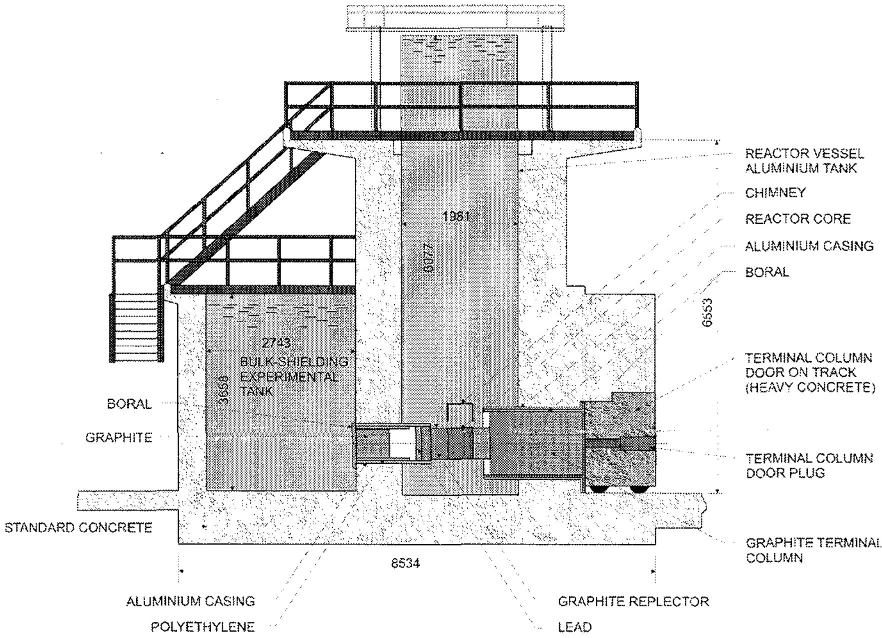
3 days/ 2 weeks

Technical Data

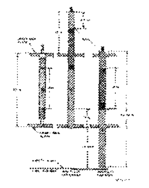
- Thermal Power : 2000 KW
- Fuel Element : U –235 (38, 55 & 99 gram) per element
- Fuel Element in the Core : 107 elements
- Moderator : H_2O & Z_rH
- Coolant : Light Water
- Reflector : Graphite & H_2O
- Control rod : B_4C, 5 rod
- Maximum Neutron Flux :
  - CT (A-1) : $5{,}18 \times 10^{13}$ n/cm^2.sec.
  - E-8 : $2{,}57 \times 10^{13}$ n/cm^2.sec.
  - E-15 : $3{,}40 \times 10^{13}$ n/cm^2.sec.
  - E-23 : $2{,}56 \times 10^{13}$ n/cm^2.sec.
  - Pneumatic : $2{,}46 \times 10^{13}$ n/cm^2.sec.
  - Lazy Susan : $8{,}34 \times 10^{13}$ n/cm^2.sec.



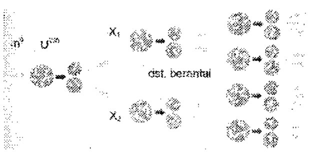
HORIZONTAL SECTION REACTOR TRIGA-MARK II



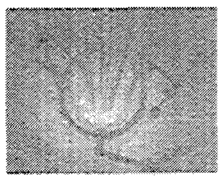
VERTICAL SECTION REACTOR TRIGA-MARK II



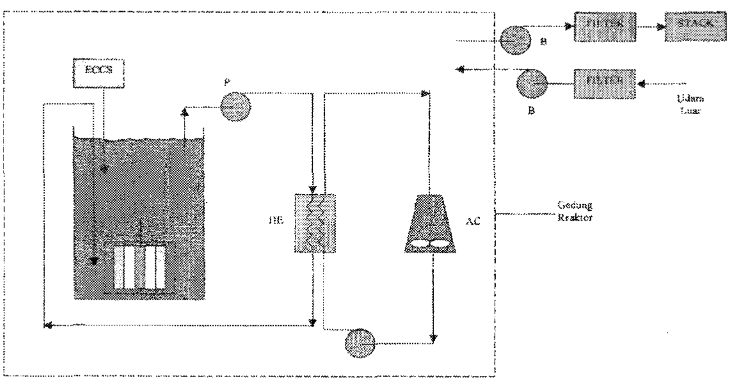
Gambar 4 Elemen Bakar, Batang Kendali dan Teras Reaktor TRIGA 2000



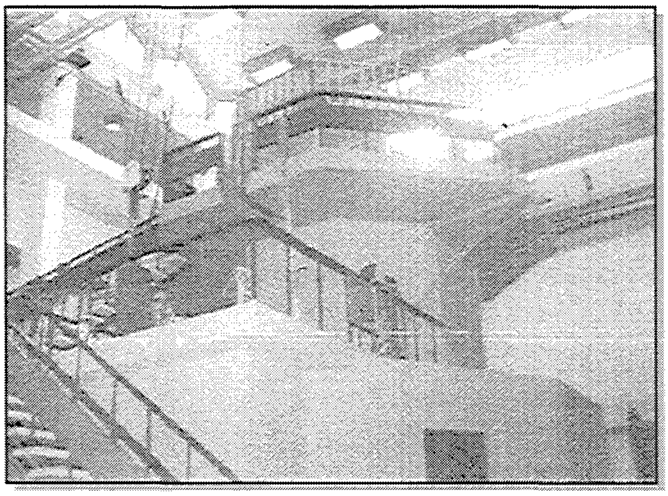
Gambar 5 Mekanisme Reaksi Inti di dalam Reaktor



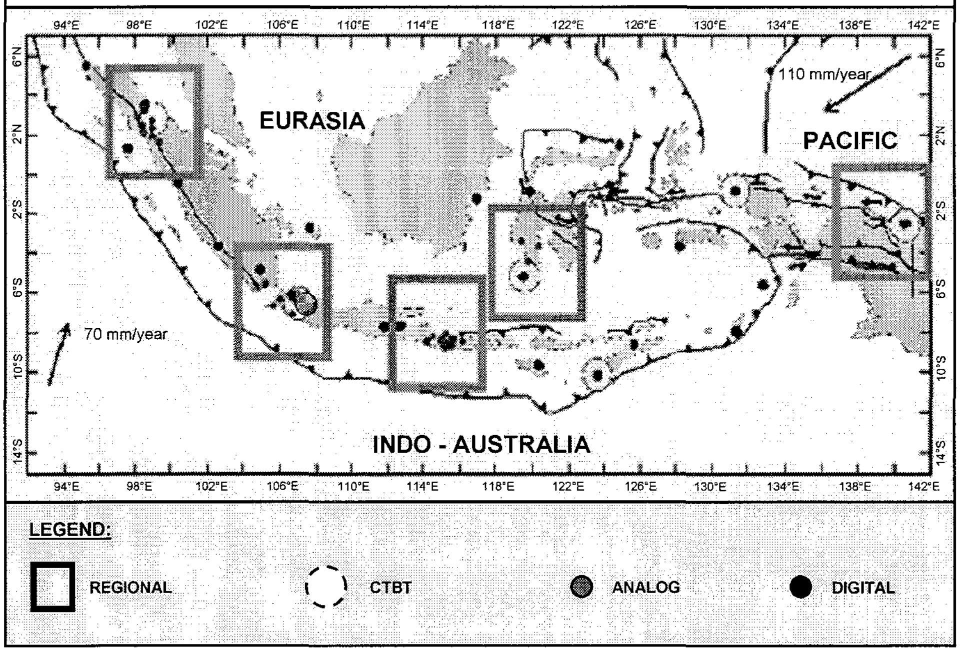
Gambar 6 Keadaan Teras Saat Reaktor TRIGA 2000 Beroperasi (Keluar *CERENCOV*)



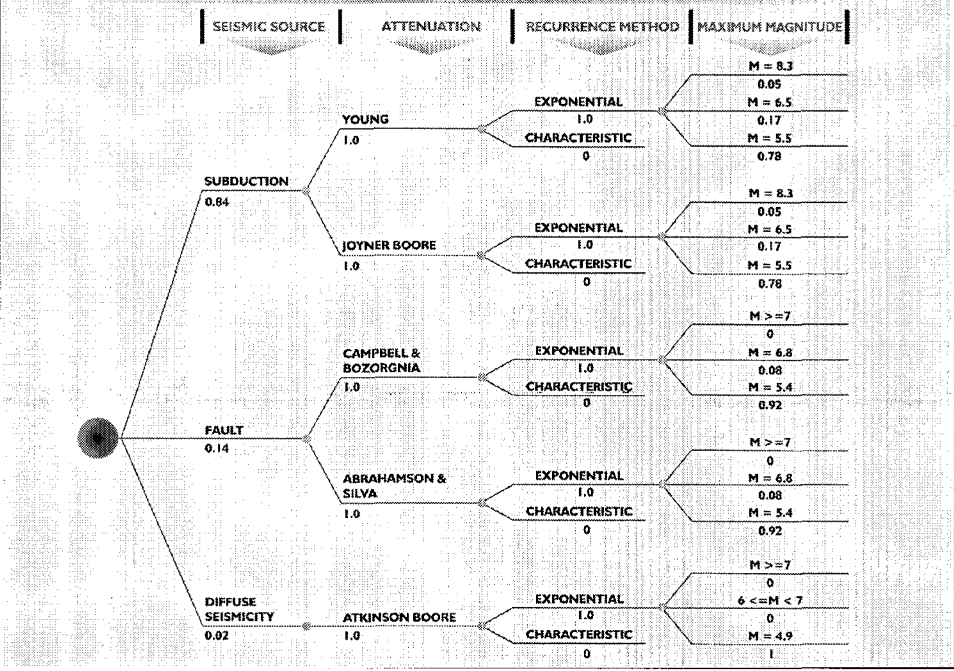
Gambar 7 Blok Diagram Sistem Reaktor TRIGA 2000 Bandung



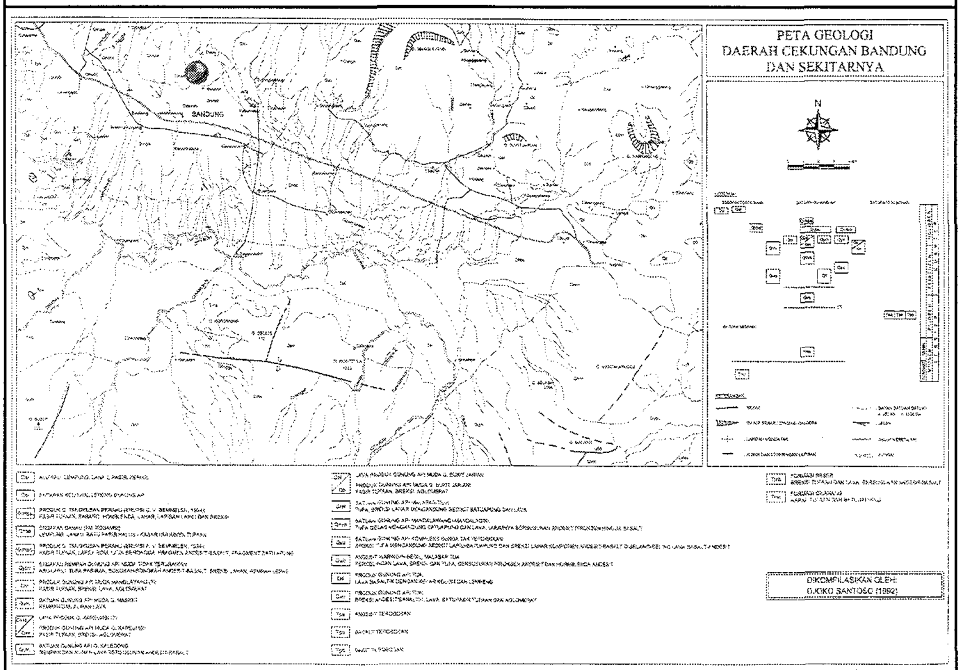
STATION NETWORK IN INDONESIA



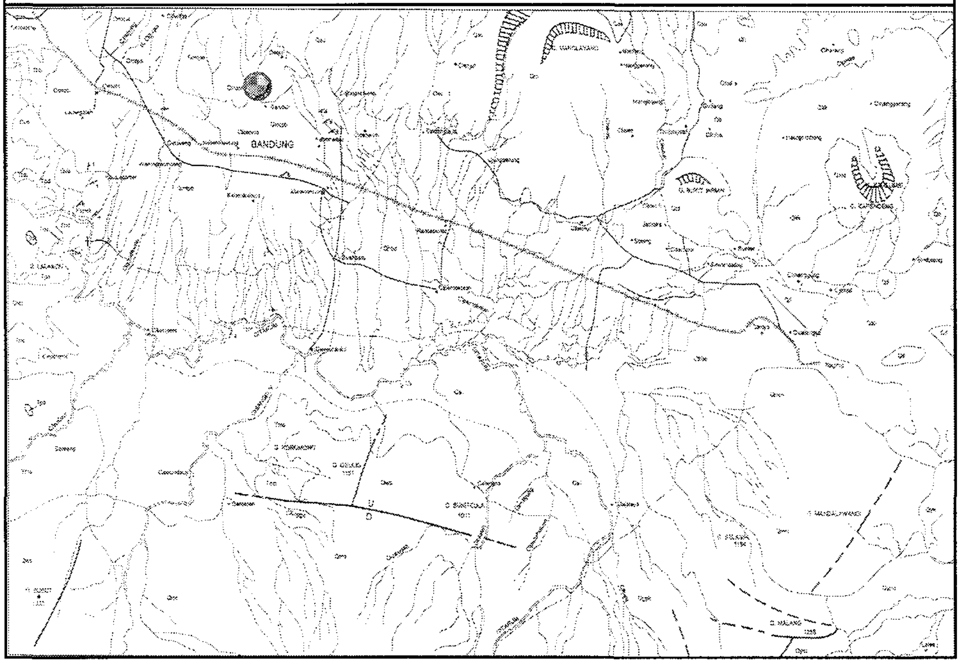
LOGIC TREE



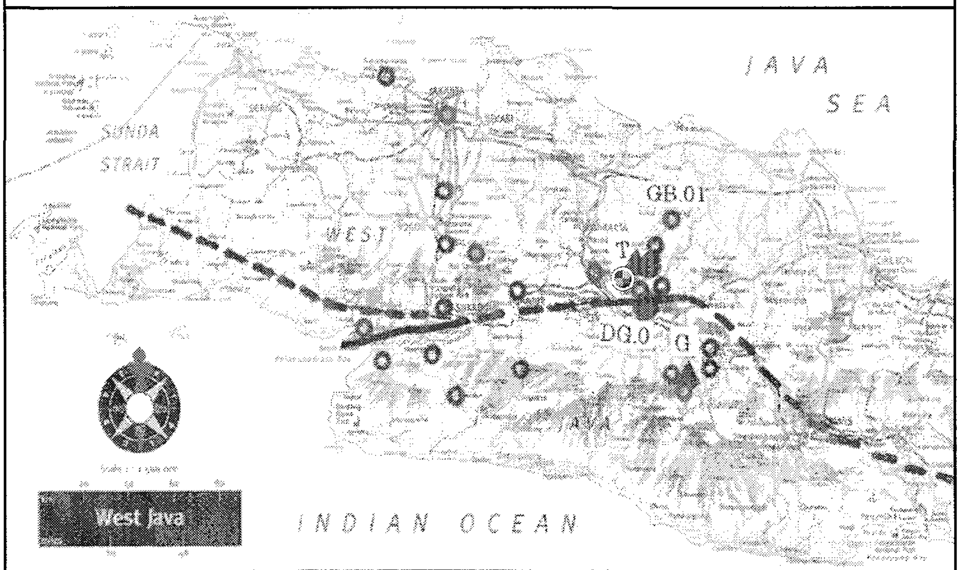
GEOLOGY



GEOLOGY



GRAVITY



Seismicity

1. **Earthquake Catalogue:**

- Arthur Witchman (0000 – 1857)
- Meteorological and Geophysics Agency (1800 – 2003)
- International Seismological Center (1900 – 2003)
- National Earthquake Information Center (NEIC) USGS (1970 – 2003)
- JISNET – Japan (1994 – 2003)

Seismicity

2. **Magnitude & Intensity Conversion:**

- Intensity → MMI Braze (1979)
- Ekstrom & Dziewonski (1998)

$M_s = \log A + 1.66 \log \Delta + 2.0$

$M_s = 1.3\ 3m_b - 1.98$

Seismicity

3. Earthquake relocation (MGA - data):

- Modified Joint Hypocenter Determination

$$(O-C)_{ij} = (t_{ij} - t_{ij}^*) - T_{ij} = \frac{\partial t_{ij}}{\partial \Delta_{ij}} \frac{\partial \Delta_{ij}}{\partial \lambda_j} d\lambda_j + \frac{\partial t_{ij}}{\partial \Delta_{ij}} \frac{\partial \Delta_{ij}}{\partial \varphi_j} d\varphi_j + \frac{\partial t_{ij}}{\partial z_j} dz_j + dt_j^* + dS_j$$

$$\sum_{i=1}^{n} S_i D_i = 0, \sum_{i=1}^{n} S_i \cos\theta_i = 0, \sum_{i=1}^{n} S_i \sin\theta_i = 0, \sum_{i=1}^{n} S_i = 0$$

Seismicity

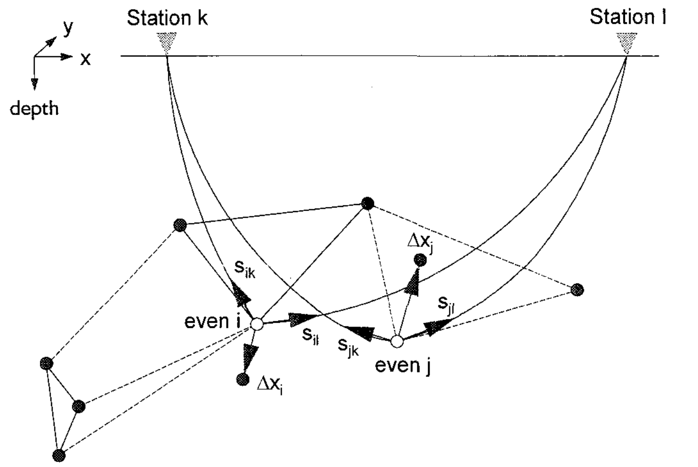
4. Earthquake relocation (MGA - data):

- Double Difference Method

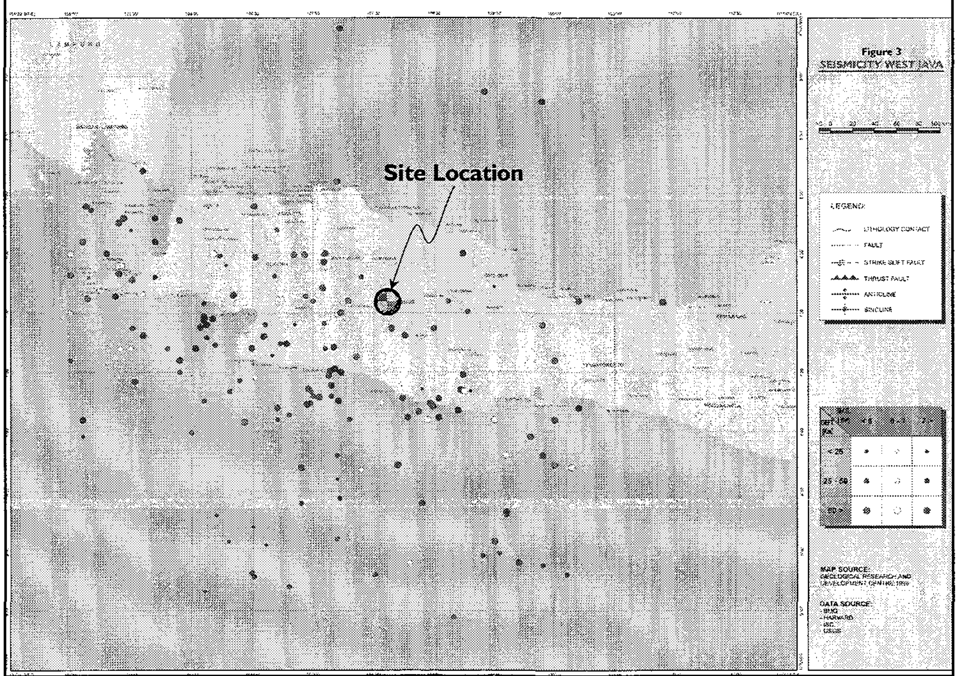
$$\left(\frac{\partial t_k^i}{\partial x} \Delta x^i + \frac{\partial t_k^i}{\partial y} \Delta y^i + \frac{\partial t_k^i}{\partial z} \Delta z^i + \frac{\partial t_k^i}{\partial t} \Delta t^i \right) - \left(\frac{\partial t_k^j}{\partial x} \Delta x^j + \frac{\partial t_k^j}{\partial y} \Delta y^j + \frac{\partial t_k^j}{\partial z} \Delta z^j + \frac{\partial t_k^j}{\partial t} \Delta t^j \right)$$

$$= \left(t_k^i - t_k^j \right)^{obs} - \left(t_k^i - t_k^j \right)^{cal}$$

Double Difference Method



SEISMICITY



Site Condition

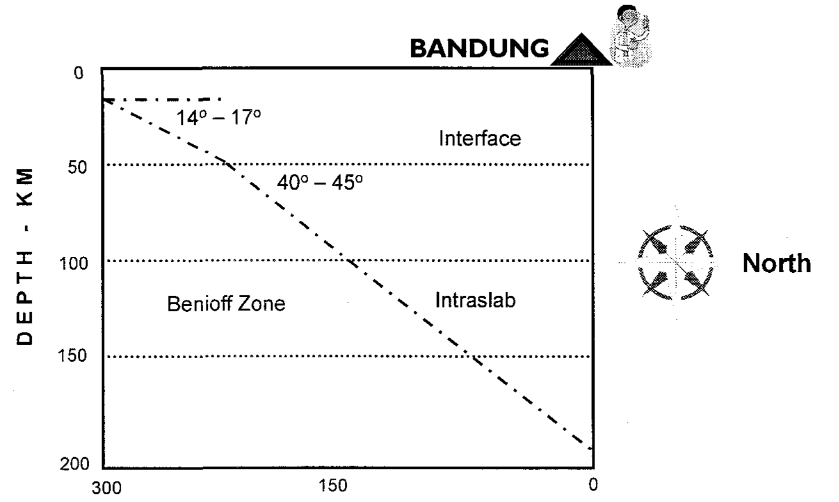
- ➢ **Nuclear Site**
- ➢ **Vs = 1050 m/s**
- ➢ **Rock**

Seismic Source Zone

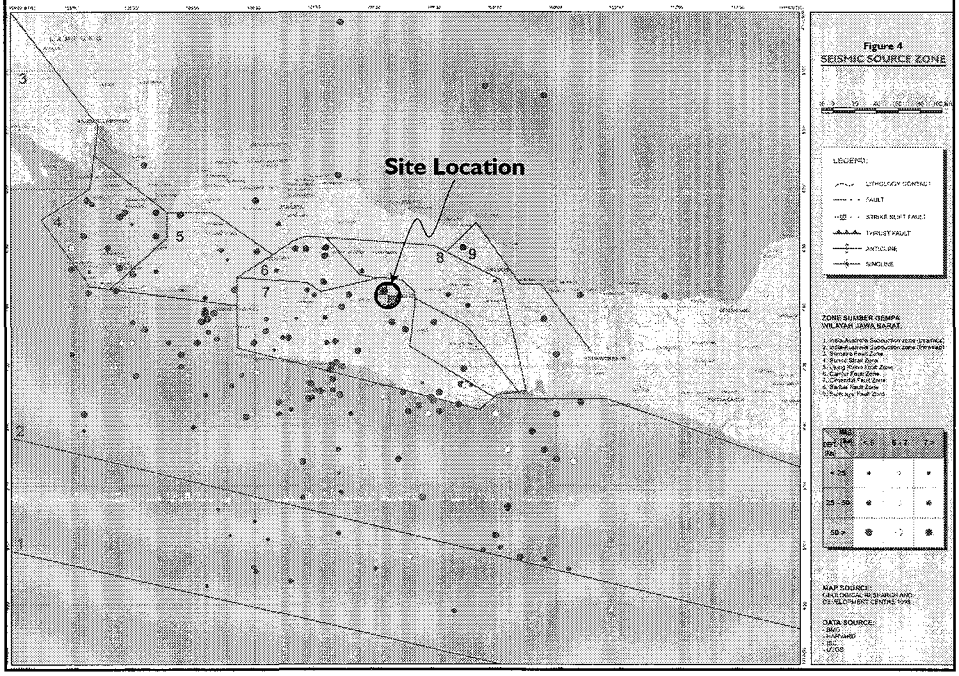
Parameter:

- ◈ Earthquake Historical
- ◈ Earthquake distribution
- ◈ Maximum & Minimum Magnitude
- ◈ b-value, Gutenberg- Richter
- ◈ Activity rate
- ◈ Earthquake depth
- ◈ Tectonic setting
- ◈ Earthquake Source (Fault/Subduction)
- ◈ Diffuse Seismicity

Earthquake Source Model

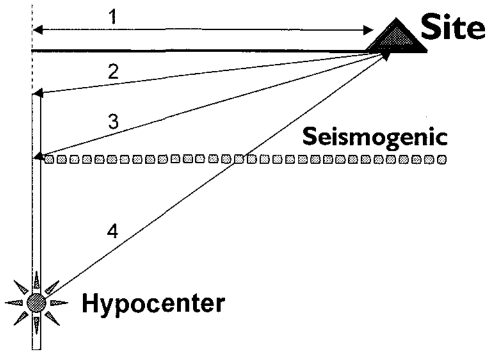


SEISMIC SOURCE ZONE

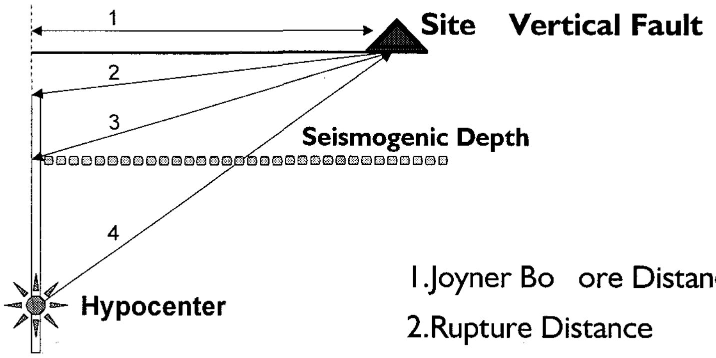


Earthquake Source Model

$$d_i = \begin{cases} \frac{1}{2}\left[H_{top} + H_{bot} - W \sin(\gamma)\right] & \text{for } d_i \geq H_i \\ H_1 & \text{otherwise} \end{cases}$$



Closest Distance



1.Joyner Bo ore Distance
2.Rupture Distance
3.Seismogenic Distance
4.Hypocenter Distance

Magnitude recurrence model

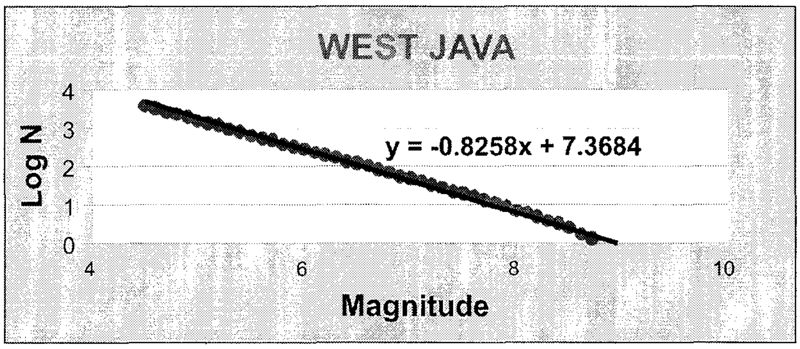
$$\log\,[n(M)] = a - bM$$

$$\beta = b\,\ln 10$$

$$N(\geq M) = \alpha \frac{\exp[-\beta(M - M_{min})] - \exp[-\beta(M_{max} - M_{min})]}{1 - \exp[-\beta(M_{max} - M_{min})]}$$

$$b = \frac{\log_{10} e}{(\overline{M} - M_{min})}$$

b-value



b-value for West Java = 0.83

Focal Mechanism

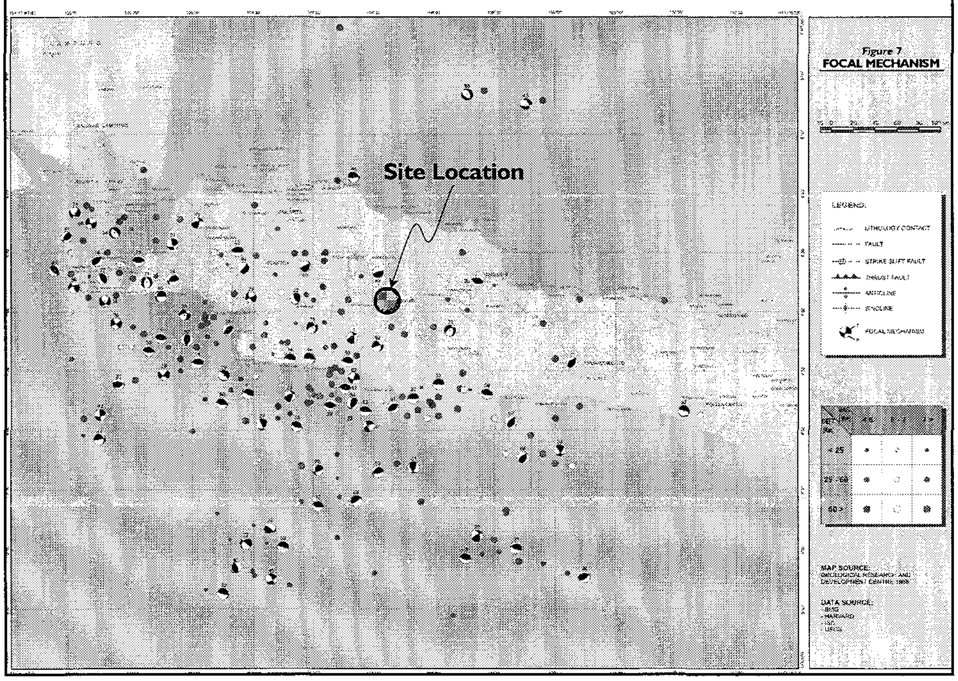
Parameter:

- Event Earthquake
- Mw = Magnitude Moment
- Strike, Slip, Dip - Rake
- Earthquake Depth

Calculation & Plotting:

- Centroid Moment Tensor (CMT)
- Focmec

FOCAL MECHANISM



Rupture Length

$$L = 10^{(0.59M_{max} - 2.44)}$$
$$W = 10^{(0.32M_{max} - 1.01)}$$

$$M_{max} = 5.08 + 1.16L$$
$$T_{max} = (1000 / slip\ rate)\, 10^{(5.46 + 0.82M_{max})}$$
$$N(M_{max}) = \frac{1}{T_{max}} = 10^{(a - bM_{max})}$$

Attenuation

Seismic Source Zone

- Shallow crustal Earthquake
- Subduction
- Diffuse Seismicity

Shallow crustal Earthquake

Campbell & Bozorgnia, 2003

$$\ln(Y_H) = C_1 + f_1(M) + C_4 \ln\sqrt{f_2(M, r_{seis}, S)} + f_3(F) + f_4(S) + f_5(H_W, F, M, r_{seis}) + \varepsilon$$

- Sadigh (1997)
- Campbell (1997)
- Boore, Joyner & Fumal (1997)
- Abrahamson & Silva (1997)
- Spudigh (1997)

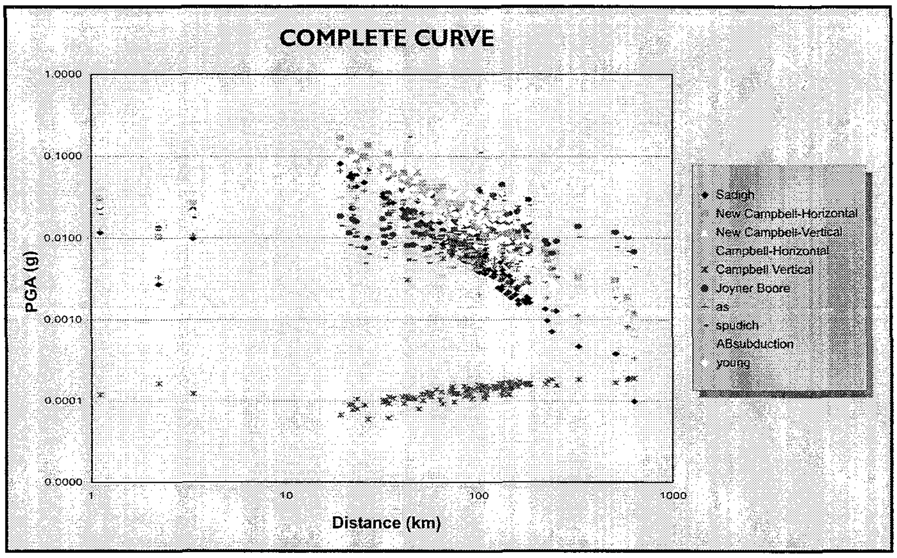
Subduction

Young, et.al., 1997

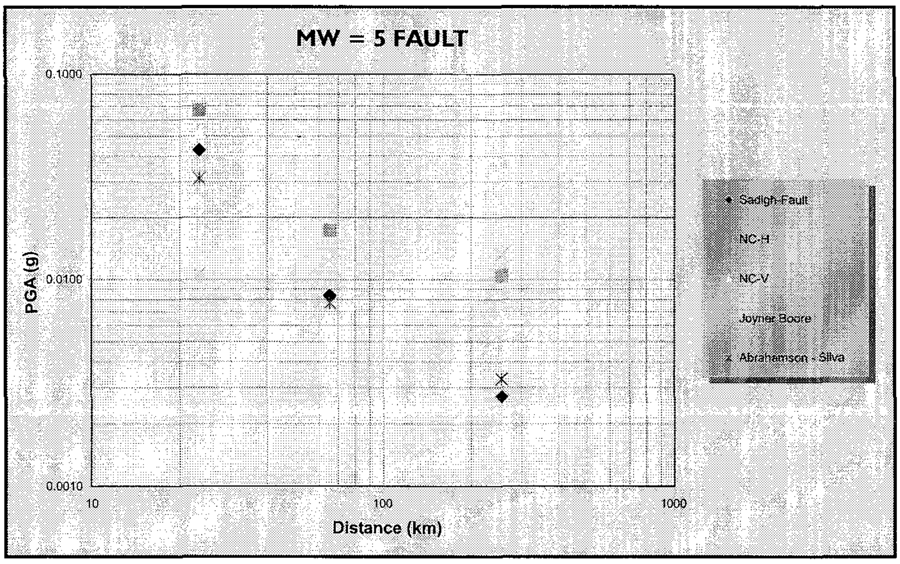
$$\ln(Y) = 0.2418 + 1.414M + C_1 + C_2(10 - M)^3 + C_3 \ln(r_{rup} + 1.7818e^{0.554M}) + 0.00607h + 0.3846Z_T$$

- Atkinson & Boore (1997)

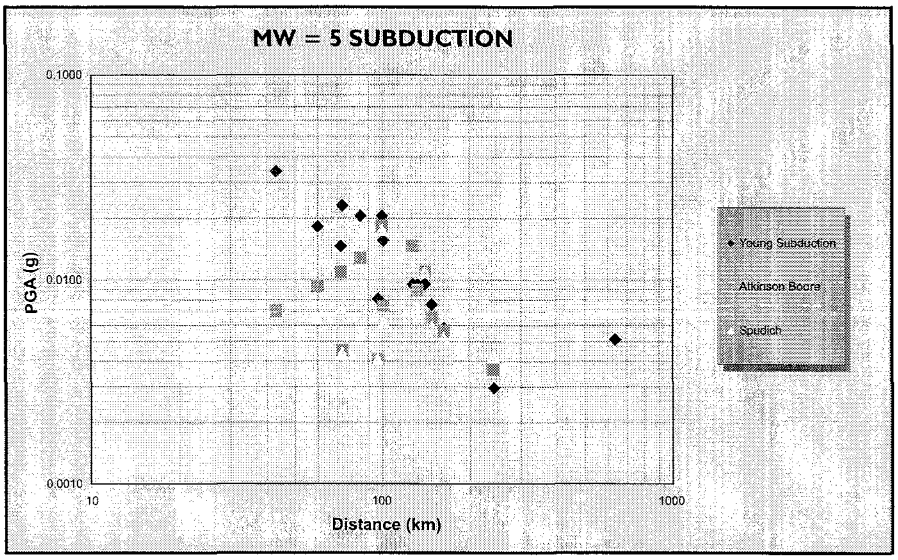
Attenuation Curve



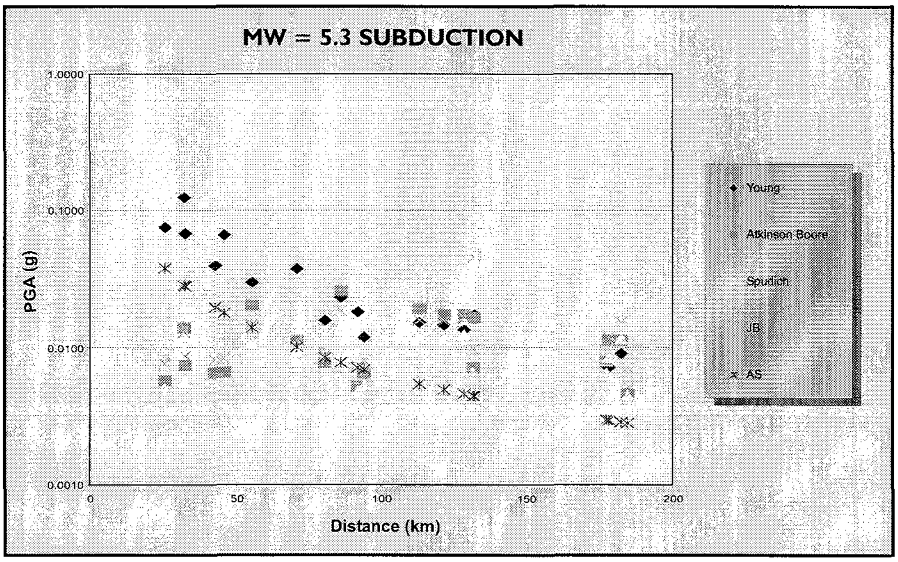
Attenuation Curve



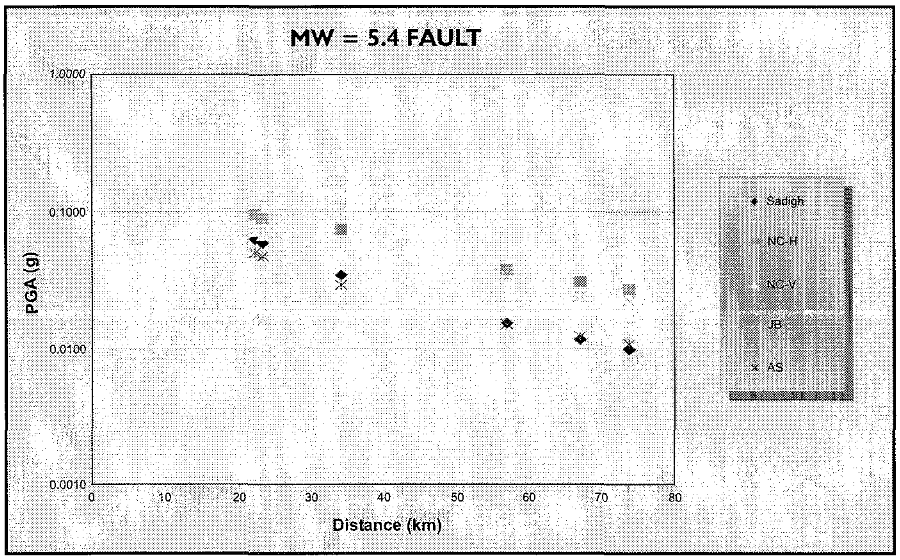
Attenuation Curve



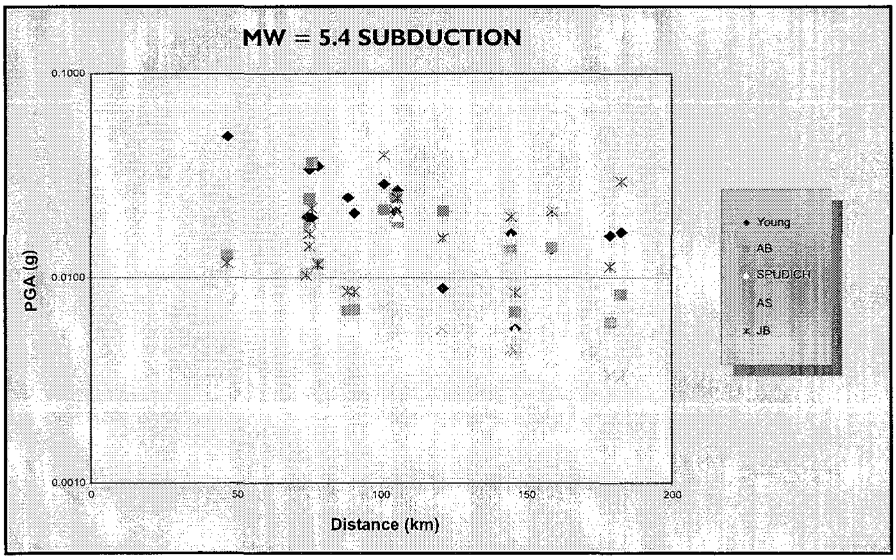
Attenuation Curve



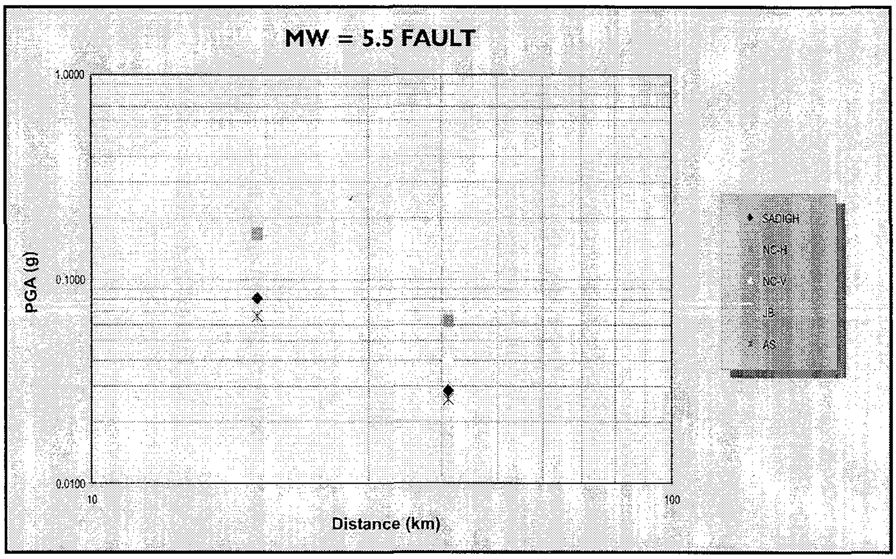
Attenuation Curve



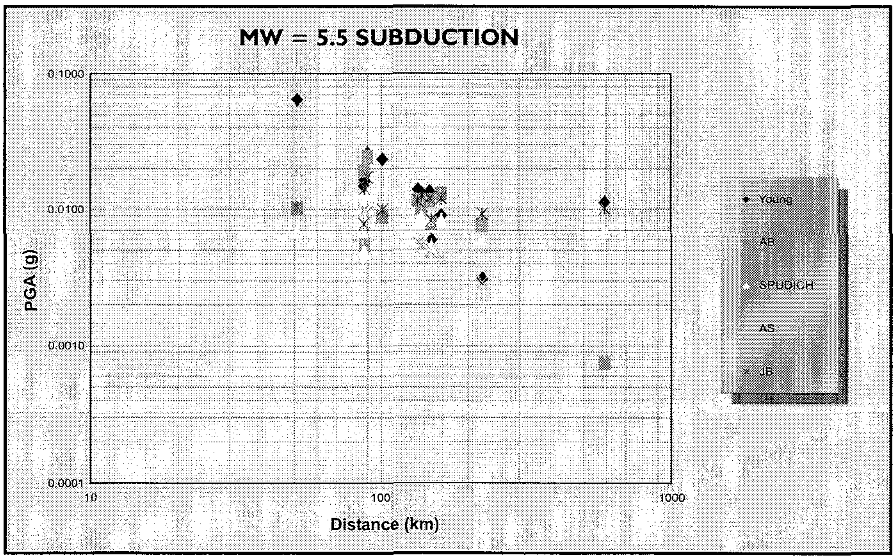
Attenuation Curve



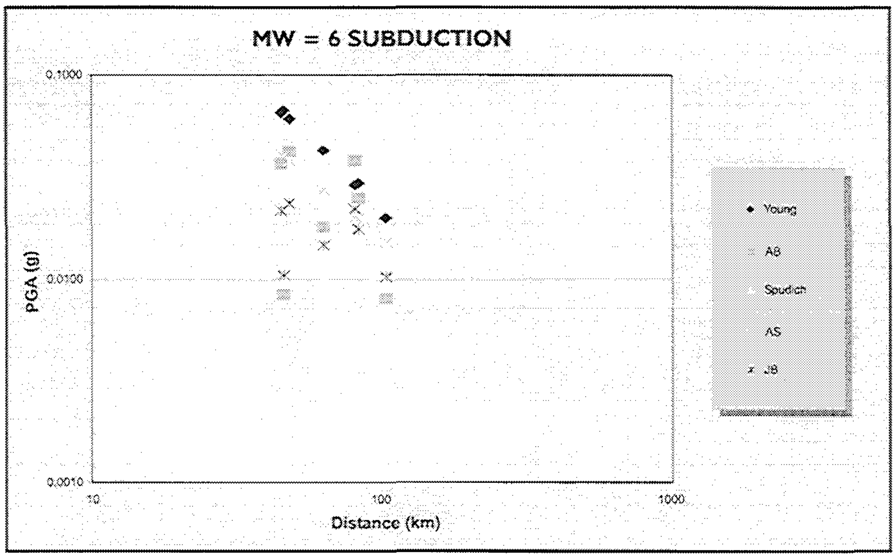
Attenuation Curve



Attenuation Curve



Attenuation Curve



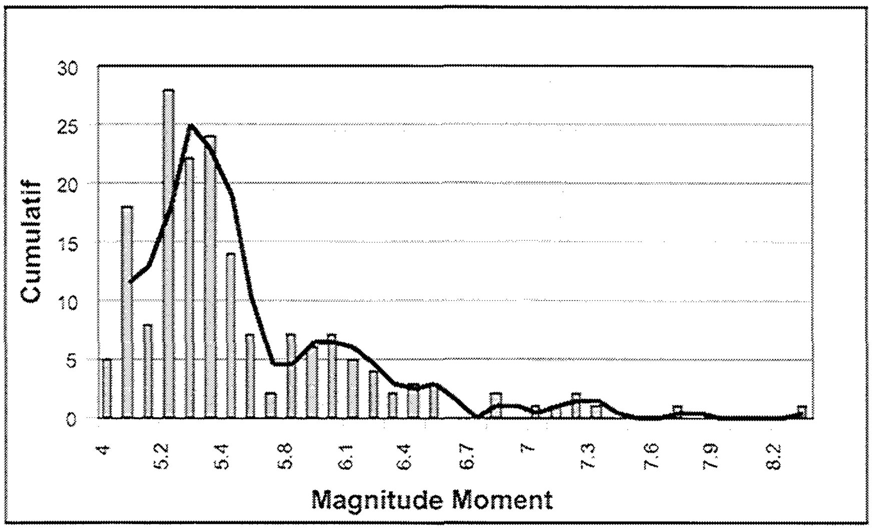
Maximum Earthquake

FAULT	RL (KM)	M_{Max} (RS)	SLIP RATE mm/year	SADIGH (g)	C&B (g)	A&S (g)
Lembang	24.9	6.69	2.00	0.219	0.354	0.204
Baribis	-	6.00	2.00	0.007	0.033	0.013
Cimandiri	100	7.40	2.00	0.008	0.039	0.024
Bumiayu	175	7.68	2.00	0.0241	0.105	0.057

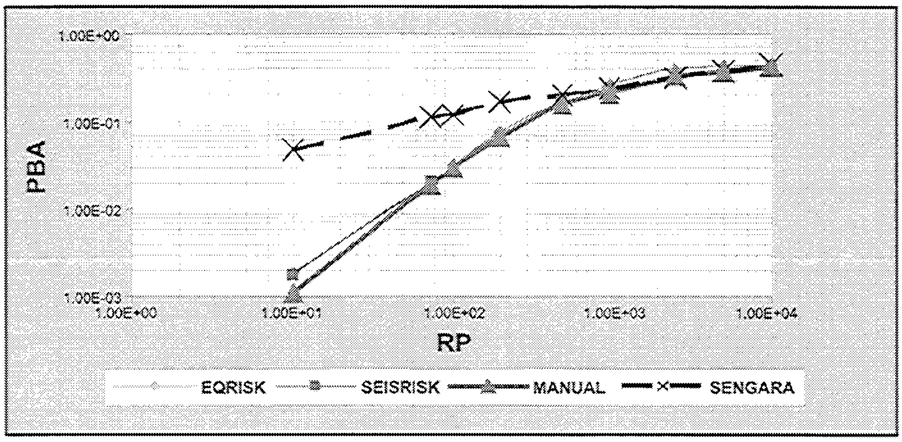
Maximum Earthquake

SUBDUCTION	RL (KM)	M_{Max} (RS)	SLIP RATE mm/year	YOUNG (g)	J&B (g)	A&B (g)
IA	-	8.3	70	0.266	0.091	0.218

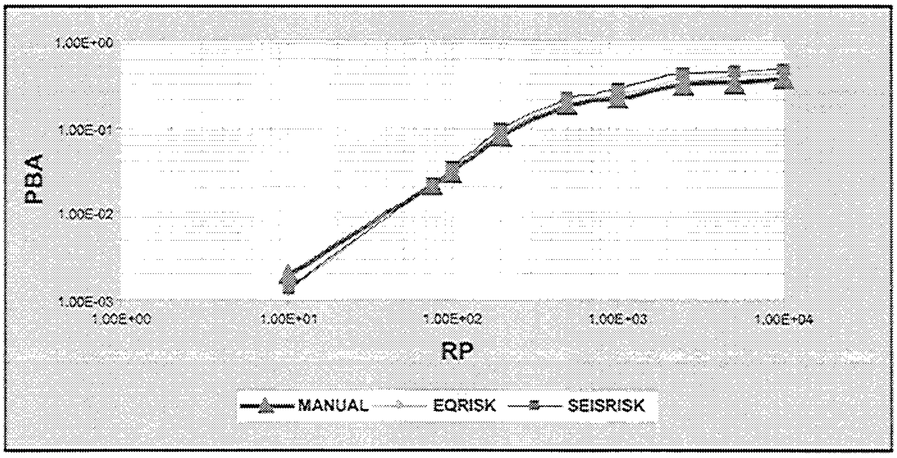
Magnitude Distribusion 0000-2004



West Java Subduction



West Java Fault



Probability

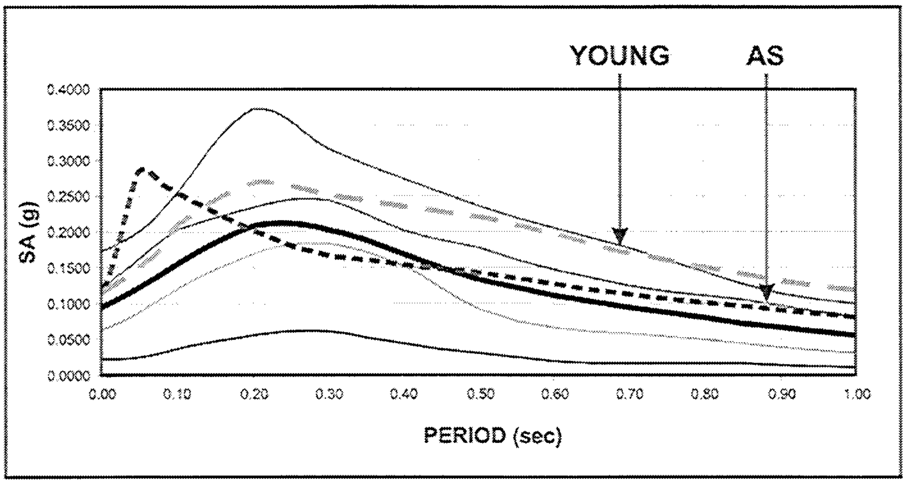
$$P[Y] = \iint p(Y \mid s, r) f_S(s) f_R(r) ds\, dr$$

$$P_p(\ln Y, T) = 1 - e^{(-R_{tot} T)}$$

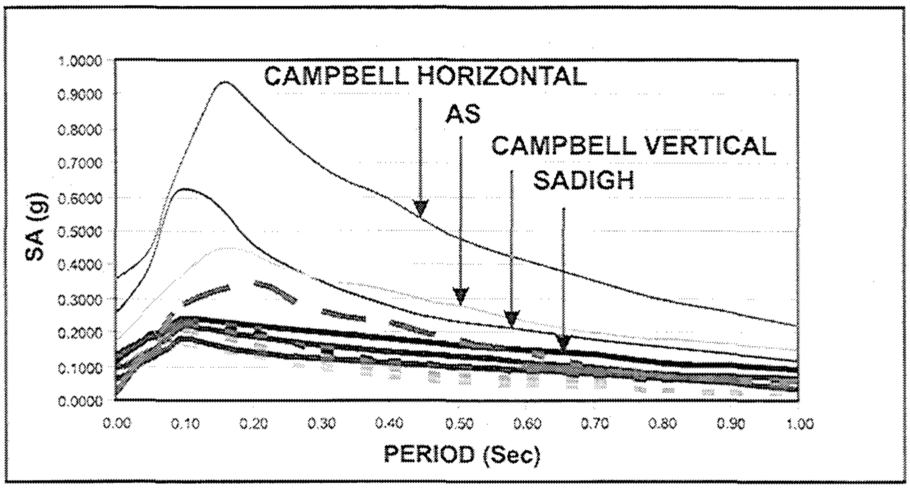
Software:

- EQRISK (Mc Guire, 1976)

Subduction

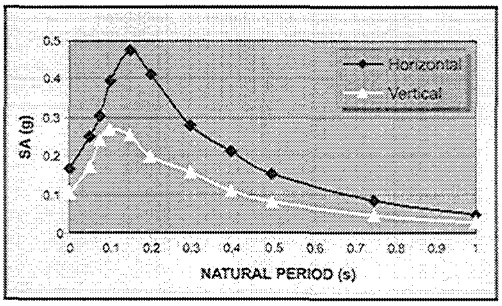


Fault



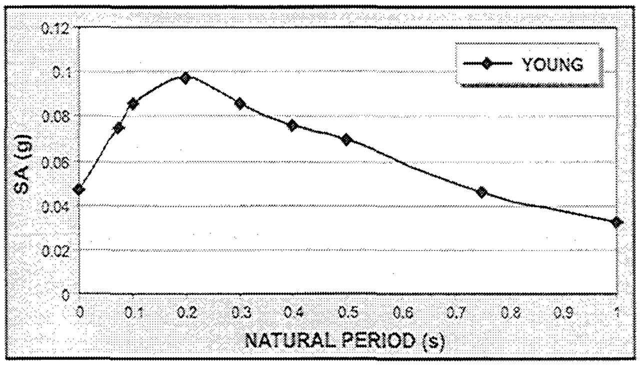
Kuningan Earthquake

Campbell	Horizontal	σ	Vertical	σ
0	0.157005	0.535	0.104341	0.59
0.05	0.250191	0.555	0.17241	0.646
0.075	0.303904	0.567	0.24222	0.646
0.10	0.394641	0.573	0.269998	0.646
0.15	0.474705	0.589	0.253642	0.646
0.20	0.412413	0.596	0.199182	0.646
0.30	0.279889	0.599	0.157921	0.646
0.40	0.211982	0.602	0.10956	0.646
0.50	0.153333	0.605	0.081747	0.646
0.75	0.084175	0.636	0.046374	0.646
1.0	0.047582	0.636	0.026714	0.646
1.5	0.019104	0.636	0.013204	0.646
2.0	0.010762	0.636	0.007468	0.646
3.0	0.005772	0.636	0.004244	0.646
4.0	0.003662	0.636	0.002661	0.646



India Australia Subduction

Young	SA	σ
0	0.046839	0.4
0.075	0.074883	0.4
0.1	0.085806	0.4
0.2	0.097292	0.4
0.3	0.085441	0.4
0.4	0.076122	0.45
0.5	0.069342	0.45
0.75	0.046347	0.45
1	0.032769	0.45
1.5	0.01887	0.45
2	0.01205	0.45
3	0.005219	0.45



Effect of Subduction Mechanism

SHA for Subduction
Mw=5.5

T	100	200	300	500	1000	2500	5000	10000
0.00	0.0197	0.0601	0.1153	0.1669	0.2451	0.2742	0.2967	0.3890
0.10	0.0344	0.1142	0.1945	0.2497	0.3869	0.4611	0.5006	0.6092
0.20	0.0549	0.1661	0.2286	0.3693	0.5577	0.7237	0.7988	0.9015
0.30	0.0590	0.1795	0.2402	0.3147	0.4701	0.5737	0.6779	0.7896
0.40	0.0439	0.1475	0.1959	0.2716	0.4266	0.4923	0.5256	0.6431
0.50	0.0296	0.0868	0.1692	0.2316	0.3112	0.4033	0.4063	0.5044
0.60	0.0188	0.0630	0.1382	0.1968	0.2416	0.3028	0.3405	0.4375
0.70	0.0164	0.0549	0.1162	0.1698	0.2103	0.2528	0.2871	0.3517
0.80	0.0151	0.0464	0.1030	0.1371	0.1921	0.2320	0.2355	0.2931
0.90	0.0115	0.0350	0.0871	0.1066	0.1635	0.1749	0.2019	0.2461
1.00	0.0109	0.0268	0.0717	0.0942	0.1508	0.1667	0.1876	0.2204

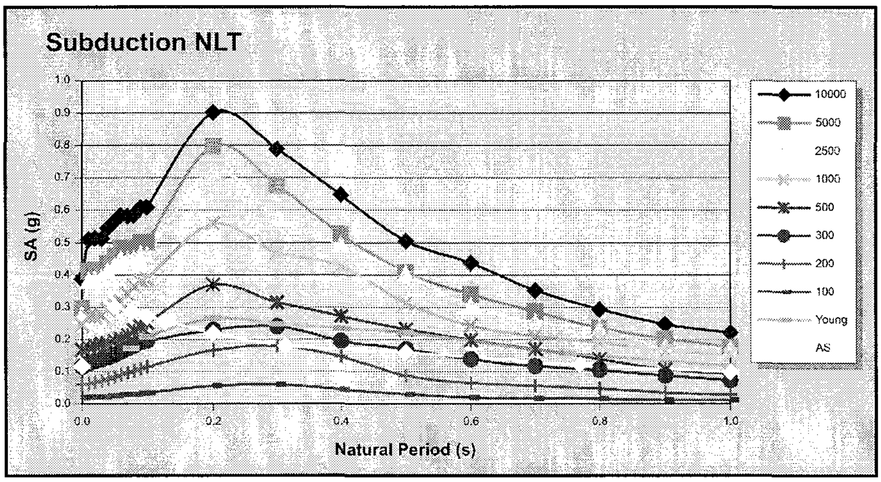
Young (1977)

T	SA(g)
0	0.114287
0.075	0.17111
0.1	0.209981
0.2	0.265703
0.3	0.249132
0.4	0.23311
0.5	0.220205
0.75	0.157144
1	0.116637
1.5	0.071713
2	0.048096
3	0.022238

Abrahamson & Silva (1977)

T	SA(g)
2	0.044669
1.25	0.081013
1	0.098174
0.769231	0.120142
0.5	0.158233
0.3125	0.17984
0.2	0.217914
0.126582	0.256319
0.1	0.269779
0.076923	0.285913
0.05	0.300906
0	0.117482

Effect of Subduction Mechanism



Effect of Fault Mechanism

SHA Horizontal
for Fault Mw=5.4

T - Horizontal	100	200	300	500	1000	2500	5000	10000
0.00	0.0638	0.0952	0.1260	0.1709	0.2108	0.3045	0.3305	0.4842
0.10	0.1785	0.2184	0.2354	0.2939	0.4593	0.7270	0.8076	0.9903
0.20	0.1394	0.1881	0.2209	0.3435	0.5216	0.7932	0.8691	1.0502
0.30	0.1195	0.1590	0.1988	0.2712	0.4077	0.6271	0.7671	0.9082
0.40	0.1094	0.1435	0.1820	0.2131	0.3373	0.5003	0.6538	0.8170
0.50	0.0993	0.1283	0.1611	0.1816	0.2748	0.4321	0.5467	0.7137
0.60	0.0877	0.1076	0.1489	0.1588	0.2510	0.4053	0.4544	0.5912
0.70	0.0771	0.0942	0.1319	0.1486	0.2405	0.3658	0.4009	0.5047
0.80	0.0617	0.0783	0.1090	0.1072	0.1821	0.2769	0.3034	0.4069
0.90	0.0507	0.0685	0.1006	0.0782	0.1397	0.2124	0.2328	0.3541
1.00	0.0297	0.0646	0.0853	0.0563	0.0993	0.1526	0.1735	0.2403

Effect of Fault Mechanism

SHA Vertical for Fault Mw=5.4

T - Horizontal	100	200	300	500	1000	2500	5000	10000
0.00	0.0573	0.0786	0.1012	0.1439	0.1691	0.2051	0.2652	0.4077
0.10	0.1540	0.1902	0.2183	0.2850	0.4012	0.6324	0.7068	0.8590
0.20	0.1199	0.1530	0.1896	0.2991	0.3912	0.6698	0.7713	0.9501
0.30	0.0788	0.1017	0.1331	0.2045	0.3205	0.5175	0.6159	0.7621
0.40	0.0568	0.0788	0.1001	0.1675	0.2755	0.3836	0.4624	0.5954
0.50	0.0414	0.0621	0.0873	0.1463	0.2337	0.3153	0.3903	0.5134
0.60	0.0345	0.0502	0.0732	0.1259	0.1853	0.2827	0.3681	0.4689
0.70	0.0281	0.0472	0.0599	0.1025	0.1370	0.2300	0.3074	0.4093
0.80	0.0161	0.0421	0.0467	0.0790	0.1147	0.1557	0.2336	0.3189
0.90	0.0100	0.0372	0.0445	0.0570	0.0899	0.1392	0.1644	0.2583
1.00	0.0087	0.0322	0.0409	0.0438	0.0693	0.1015	0.1482	0.2031

Effect of Fault Mechanism

Campbell & Bozorgnia (2003)

	Horizontal	*Vertical*
T	SA(g)	SA(g)
0	0.354417	0.255559
0.05	0.448695	0.405484
0.075	0.590795	0.558249
0.1	0.715285	0.622379
0.15	0.927541	0.572102
0.2	0.872616	0.458424
0.3	0.686981	0.351391
0.4	0.59113	0.280741
0.5	0.481097	0.236017
0.75	0.326486	0.165761
1	0.220056	0.113965
1.5	0.117607	0.075049
2	0.078887	0.050552
3	0.045625	0.030985
4	0.030498	0.020464

Abrahamson & Silva (1977)

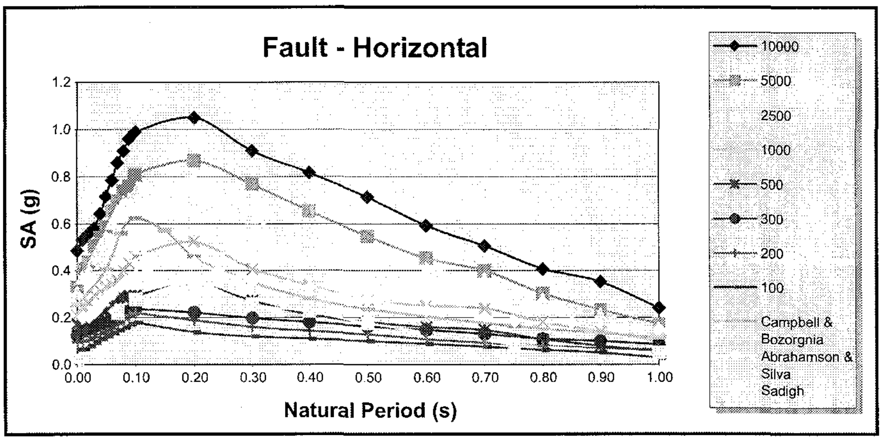
Horizontal	
T	SA(g)
5.000	0.015712
4.000	0.023288
3.000	0.03899
2.000	0.074448
1.500	0.086373
1.000	0.149587
0.850	0.175991
0.750	0.185895
0.600	0.231586
0.500	0.277169
0.460	0.290944
0.400	0.326833
0.360	0.335566
0.300	0.356916
0.240	0.399193

Horizontal	
T	SA(g)
0.200	0.434868
0.170	0.446123
0.150	0.448408
0.120	0.407973
0.100	0.376157
0.090	0.356324
0.075	0.334326
0.060	0.30331
0.050	0.280957
0.040	0.253848
0.030	0.224375
0.020	0.203664
0.010	0.203664

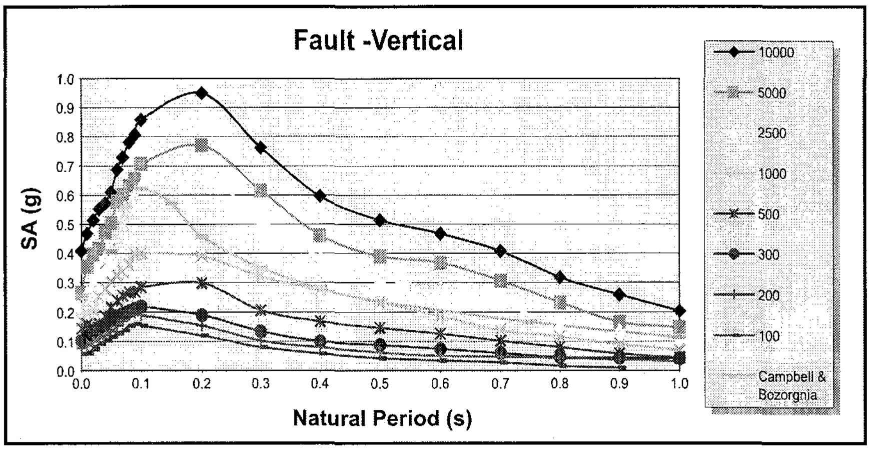
Sadigh

Horizontal	
T	SA(g)
0	0.019800
0.07	0.219731
0.1	0.276157
0.2	0.346123
0.3	0.256916
0.4	0.226833
0.5	0.177169
0.75	0.085895
1	0.049587
1.5	0.036268
2	0.021959
3	0.020161
4	0.017671

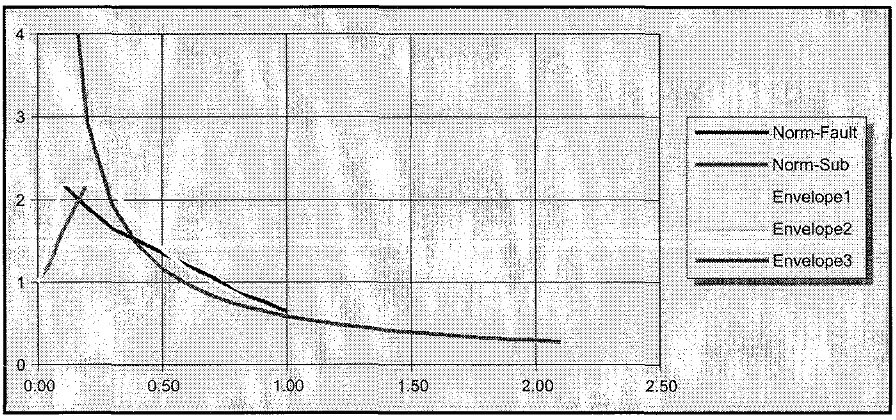
Effect of Fault Mechanism



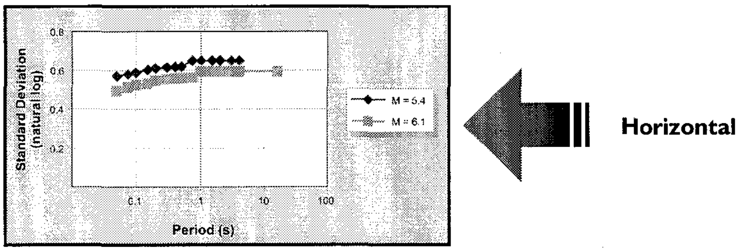
Effect of Fault Mechanism

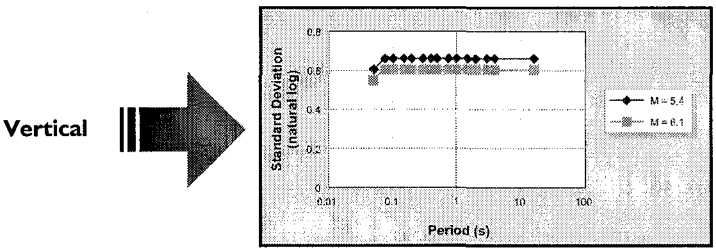


Target Spectrum



Standard deviation of spectral acceleration (σ_{lnY}) from this study for horizontal and vertical component with Mw = 5.4 and Mw =6.1 (Fault case)





Conclusions

- A new seismic hazard assessment for West Java has been carried out, taking into account a recently revised earthquake catalogue and a seismotectonic zonation defined by tectonic zonation and seismicity.
- Different seismicity models of occurrence are applied to deduce the seismicity behaviour of the West Java Teritory. Therefore, the seismic hazard has been calculated by using a model based on the Cornell (1968) method, later modified by McGuire (1976), and adapted for the possibility of using the Young (1997); Campbell & Bozorgnia (2004) attenuation law and a truncated Gutenberg-Richter recurrence model.

References

- IAEA (International Atomic Energy Agency)´ Evaluation of Seismic Hazards for Nuclear Power Plants Safety Standards Series No. NS-G-3.3 2002, Date of Issue: 21 March 2003
- Abrahamson, N.A., and W.J. Silva., (1997), "Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes"., Bulletin of Seismological Society of America Vol. 68, No. 1.
- Abrahamson, N.A., (2003).," State of The Practice of Seismic Hazard Evaluation". Hand note
- Atkinson, G.M. and D. M. Boore (1998) Evaluation of Models for Earthquake Source Spectra in Eastern North America, Bulletin of Seismological Society of America Vol. 88.

References

- Atkinson, G.M. and Boore, D.M.,(2003), "Empirical Ground-Motion Relations for Subduction-Zone Earthquakes and Their Application to Cascadia and Other Regions" BSSA, Vol. 93, pp. 1703-1729.
- Bender and Perkins, (1772) SEISRISK III: A Computer Program for Seismic Hazard Estimation"
- Boore, D.M., Joyner, W.B., Fumal, T. E., (1977), "Equation for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquake; A Summary of Recent Work, Bulletin of Seismological Society of America Vol. 68, No. 1.
- Bozorgnia, Y. and Campbell, K.W., (2004), "The Vertical-to-Horizontal Response Spectral Ratio and Tentative Procedures for Developing Simplified V/H and Vertical Design Spectra", Journal of Earthquake Engineering, Vol. 8.

References

- Campbell K.W., (1997), "Attenuation Relationships for Shallow Crustal Earthquakes Based on California Strong Motion Data" Bulletin of Seismological Society of America Vol. 68, No.1.
- Campbell, K.W., (1997), "Empirical Near-Source Attenuation Relationships for Horizontal and Vertical Components of Peak Ground Acceleration, Peak Ground Velocity, and Pseudo-Absolute Acceleration Response Spectra., Bulletin of Seismological Society of America Vol. 68, No. 1.
- Campbell, K.W., (2003), " Engineering models of Strong Ground Motion", Earthquake Engineering Handbook (W.F. Chen and C. Seawthorn, eds.), 76 pp.
- Campbell, K.W., Bozorgnia, Y. and Bertero, V., (2004). "Appendix Supplemental Ground Motion (Attenuation) Relations",. Earthquake Engineering Seismology to Performance-Based Engineering, Chapter 5.

References

- Carl J.S., and etc., (2001), "Probabilistic Seismic Hazard Analyses for Ground Motion and fault Displacement at Yucca Mountain, Nevada". Earthquake Spectra, Volume 17. No. 1.
- Crouse, C.B., (1991), "Ground Motion Attenuation Equation for Earthquakes on the Cascadia Subduction Zone", Earthquake Spectra, Vol & No. 2.
- Ekström, G. and Dziewonski, A.M., (1988), "Evidence of Bias in estimations of earthquake size", Reprinted from Nature, Vol. 332, No. 6162, pp. 319-323.
- Ellsworth, W.L. etc., (1999), "A physically-Based Earthquake Recurrence Model for Estimating of Long Term Earthquake Probabilities, Workshop on Earthquake Recurrence: State of the ART and Directions for the future, Rome Italy.
- EERI Committee on Seismic Risk, (1989),"The Basics of Seismic Risk Analysis, Earthquake Spectra, Vol. 5, No. 4.

References

- Gasperini., Paolo, Bernardini, F., Valensise,. G and Boschi, E., (1998), "Defining Seismogenic Sources from Historical Earthquake Felt Reports"., Bulletin of Seismological Society of America.
- Hanks, T.C and Cornell, C.A., (1997)."Probabilistic Seismic Hazard Analysis: A Beginner's Guide".
- Lienert (1995), Hypocenter program for localization, USGS.
- International Atomic Energy Agency (2002), "Evaluation of Seismic Hazards for Nuclear Power Plants", Safety Series No. NS-G-3.3
- Joyner, W.B., and Boore, D.M., (1981), " Peak Horizontal Acceleration and Velocity from Strong Motion Records Including Records from the 1979 Imperial Valley, California, Earthquake",(Bulletin of Seismological Society of America Vol. 68.

References

- Kramer, S.L., (1996), "Geotechnical Earthquake Engineering", University of Washington.
- Lungu, D. Zaiccenco, A. and etc., (1997), " Seismic Hazard: Recurrence and Attenuation of Subcrustal (60-170km) Earthquake", ICCOSSAR'97.
- McGuire, R. K (1976), "EQRISK (Evaluation of Site for Earthquake Risk) Manual User's" United State Department of Interior Geological Survey.
- Ratman, N and Gafoer, S., (1998), " Geological Map of Western Part of Java", Geological Research and Development Centre, Bandung.
- Young, R.R., Chiou, S. J., Silva, W. J., Humprey, J. R., (1997), "Strong Ground Motion Attenuation Relationship for Subduction Zone Earthquake", Bulletin of Seismological Society of America Vol. 68, No.1.

Glossary

- **Acceleration.**

  The rate of change of velocity of a reference point. Commonly expressed as a fraction or percentage of the acceleration due to gravity (g) where g = 980 cm/s2.

- **Attenuation.**

  A decrease in seismic-signal amplitude as waves propagate from the seismic source. Attenuation is caused by geometric spreading of seismic-wave energy and by the absorption and scattering of seismic energy in different earth materials *(termed anelastic attenuation)*. Q and kappa are attenuation parameters used in modeling the attenuation of ground motions

Glossary

- **Benioff zone.**

  A dipping planar zone of earthquakes that is produced by the interaction of a downgoing oceanic crustal plate with a continental plate. These earthquakes can be produced by slip along the subduction thrust fault (sometimes referred to as the thrust interface fault because it is the interface between the continental plate and the oceanic plate) or by slip on faults within the downgoing plate as a result of bending and extension as the plate is pulled into the mantle. Slip may also initiate between adjacent segments of downgoing plates.

Glossary

- **Deterministic methods.**

  Refers to methods of calculating ground motions for hypothetical earthquakes based on earthquake-source models and wave-propagation methods that exclude random effects.

- **Ground motion *(shaking)*.**

  General term referring to the qualitative or quantitative aspects of movement of the Earth's surface from earthquakes or explosions. Ground motion is produced by waves that are generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the Earth and along its surface

- **Isoseismal.**

  Refering to a line on a map bounding points of equal intensity for a particular earthquake.

Glossary

- **Recurrence interval.**

  The average time span between events (such as large earthquakes, ground shaking exceeding a particular value, or liquefaction) at a particular site.

- **Seismogenic.**

  Capable of generating earthquakes

- **Standard deviation.**

  The square root of the average of the squares of deviations about the mean of a set of data. Standard deviation is a statistical measure of spread or variability.

Acknowledment

Gratitude is expressed to

The Abdus Salam International Center for Theorical Physics - Italy for hosting the workshop as well as International Atomic Energy Agency - Vienna for support & sponsoring our work.

Thanks are also expressed to National Nuclear Energy Agency Center for Research & Development of Nuclear Techniques Bandung – Indonesia for opportunity.