The sensitivity of earthquake input motion correlation with arias intensity and amplification, case study: Yogyakarta Special Region

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Abstract. Earthquake problems are a fascinating topic that discussed among the scientific and academic in the world, including of these is the parameter of a sensitivity. In this study, the sensitivity level of earthquake input motion in bedrock correlated with intensity arias and amplification occurring at the surface. The selected location of the study is an earthquake-prone area with the last record of a major earthquake in 2006, i.e., Yogyakarta Special Region. There are 3 (three) study areas with different geological environments. The analysis is determined by these steps: (1) Probabilistic Seismic Hazard Analysis/PSHA (2) disaggregation (3) selection of motion input and (4) wave propagation analysis to obtain a graph of Arias intensity and amplification value. All of those are aided by EzFrisk and DeepSoil software. The results of this study, i.e., the higher natural frequency at the site, then the lesser amplification developed. The highest amplification takes place at BH-04 which has the smallest natural frequency. On the other hand, the lowest value occurred at BH-02 on the highest natural frequency. There is a tendency that the smaller delta on the effective time arias intensity, the more significant amplification be occurred, except for Loma Prieta ground motion.

1. Introduction
Earthquake problems are a fascinating topic that discussed among the scientific and academic in the world. There are many significant earthquakes recorded struck Indonesia, especially in Yogyakarta Special Region as mentioned by scientist [1–3]. The topic of this study is parameter sensitivity due to input ground motion at bedrock correlated to arias intensity and amplification at the surface. Arias intensity parameter specified in effective time during 5-95% of occurred energy [4]. Since amplification only discussed in acceleration area. There are many research which similar using arias intensity parameter and amplification, i.e.: paper done by Syahbana et.al which looking for effect at the surface according to Chichi and Kocaeli earthquake simulation in Cilacap City [5], study by Davies et.al which finding method to distinguish shaking as result of drilling and earthquake [6], developing new way of earthquake zonation in Java Island [7] and application in slope stability analysis on Sumatera offshore [8]. To obtain the objection in this research, there are several methods conducted as mentioned following
(1) Probabilistic Seismic Hazard Analysis/PSHA (2) disaggregation (3) selection of motion input and (4) wave propagation analysis to obtain the graph of Arias intensity and amplification value.

The May 27, 2006 earthquake severely damaged Yogyakarta Special Region. Surrounding area included Bantul-Klaten which passed Opak River to the west Klaten also got terrible damage. According to [9] the oldest rock outcrops are the Kebo-Butak Formation of Oligo- Miocene age consisting of tuffaceous breccia, andesite, and agglomerates. Subsequently sediments was the Semilir Formation of Oligo-Miocene age composed of tuffaceous breccia and tuffaceous clay. Ngllaran Formation unconformably sedimented on top of Semilir Formation consisting of volcanic breccia and tuff of early to middle Miocene. Subsequently sedimented were the Sambipitu Formation (tuff, shale, siltstone), Wonosari Formation (reef limestone and calcarenites), Kepek Formation (marl and limestone), Sentolo Formation (limestone, marl sandstone). On top of them were sedimented the Quarternary volcanic material of Mount Merapi, alluvium, and colluvium (Figure 1).

The geological structures in this area are the strike-slip fault well known as the Opak fault oriented to the northeast-southwest of N 235° E/80°, where the east block relatively slips to the north, and the west block slips to the south. The width of the fault zone is approximately 2.5 Km. Besides the Opak fault, there is also another fault trending almost east-west towards the Gantiwani area. The coastal region of South Java is part of the forearc which frequently experiences earthquake shocks. The earthquakes mostly have the magnitude of Mw 4-6 and some of Mw >6. The seismic records revealed the occurrence of structural lineaments trending and northwest-southeast. Generally, the focal mechanism indicates the presence of the fault zone and downward shearing at Opak Fault. The seismicity of Yogyakarta is quite high and active, and the calculated peak ground acceleration varied from 0.380 to 0.531 g [10]. In this study, three location analyzed about their characteristic of amplification and Arias intensity due to different input motion. Its location and soil properties showed in Table 1 and Figure 1.

![Figure 1. Geological and borehole engineering location in Yogyakarta area.](image-url)
### Table 1. Soil properties at study area. [11]

| ID   | Depth (m) | Bottom Depth (m) | N-SPT | $\gamma$ (kN/m$^3$) | Atterberg Limit | Type | Vs (m/s) |
|------|-----------|------------------|-------|----------------------|-----------------|------|---------|
|      |           |                  |       |                      | LL             | PL   | PI      |         |
| BH-01|           |                  |       |                      |                |      |         |         |
| 1.5  | 1.95      | 13               | 18    |                      |                |      |         | 170     |
| 3    | 3.45      | 8                | 18.5  |                      |                |      |         | 145     |
| 4.5  | 4.95      | 10               | 19.5  |                      |                |      |         | 156     |
| 6    | 6.45      | 17               | 19    |                      |                |      |         | 186     |
| 7.5  | 7.95      | 28               | 18    |                      |                |      |         | 219     |
| 9    | 9.45      | 6                | 19.5  |                      |                |      |         | 132     |
| 10.5 | 10.95     | 53               | 19    |                      |                |      |         | 271     |
| 12   | 12.45     | 12               | 17.5  | 72                   | 43.2           | 28.8 | MH      | 153     |
| 13.5 | 13.95     | 11               | 19    |                      |                |      |         |         |
| 15   | 15.45     | 15               | 18    | 85                   | 31.7           | 53.3 | CH      | 161     |
| 16.5 | 16.95     | 50               | 19    |                      |                |      |         | 265     |
| 18   | 18.45     | 50               | 19    |                      |                |      |         | 265     |
| 19.5 | 19.95     | 50               | 17.5  | 58                   | 30.4           | 27.6 | MH      | 267     |
| 1.5  | 1.95      | 9                | 17.5  |                      |                |      |         | 151     |
| 3    | 3.45      | 13               | 19    |                      |                |      |         | 170     |
| 6    | 6.45      | 29               | 19.5  |                      |                |      |         | 222     |
| 7.5  | 7.95      | 35               | 20    |                      |                |      |         | 236     |
| 9    | 9.45      | 22               | 19.5  |                      |                |      |         | 202     |
| BH-02|           |                  |       |                      |                |      |         |         |
| 10.5 | 10.95     | 28               | 18    |                      |                |      |         | 219     |
| 12   | 12.45     | 50               | 19    |                      |                |      |         | 265     |
| 13.5 | 13.95     | 50               | 19    |                      |                |      |         | 265     |
| 15   | 15.45     | 30               | 17.5  |                      | 65             | 42.3 | 22.7    | MH      | 219     |
| 16.5 | 16.95     | 50               | 19.5  |                      |                |      |         | 265     |
| 1.5  | 1.95      | 3                | 18    | 35                   | 20.4           | 14.6 | CL      | 75      |
| 3    | 3.45      | 13               | 19    |                      |                |      |         | 170     |
| 4.5  | 4.95      | 18               | 19.5  |                      |                |      |         | 189     |
| 6    | 6.45      | 50               | 19    |                      |                |      |         | 265     |
| 7.5  | 7.95      | 9                | 19    |                      |                |      |         | 151     |
| 9    | 9.45      | 29               | 19    |                      |                |      |         | 222     |
| BH-04|           |                  |       |                      |                |      |         |         |
| 10.5 | 10.95     | 6                | 19    |                      |                |      |         | 132     |
| 12   | 12.45     | 7                | 17.5  |                      | 68             | 48.5 | 19.5    | MH      | 124     |
| 13.5 | 13.95     | 22               | 17.5  |                      | 56             | 39.9 | 16.1    | MH      | 194     |
| 15   | 15.45     | 15               | 17.5  |                      | 58             | 40.4 | 17.6    | MH      | 167     |
| 16.5 | 16.95     | 27               | 17.5  |                      |                |      |         | 210     |
| 18   | 18.45     | 9                | 17.5  |                      | 52             | 33.4 | 18.6    | MH      | 137     |
| 19.6 | 20.05     | 18               | 19.5  |                      |                |      |         | 189     |

$\gamma$: weight volume, LL: Liquid Limit, PL: Plastic Limit, PI: Plasticity Index, Type: based on USCS, Vs.: shear velocity.
2. Methods
In this paper, some steps conducted as mentioned previously. These steps are:

2.1. Preparing parameter of source earthquake
Earthquake Catalogue needed for the analysis. It contains information about magnitude, mechanism, location and time of an earthquake. The catalogue obtained from an agency which competent, private or government, in this paper, used data from National Seismic Centre (PusGen). Those data analyzed using declustering, time and distance windows to obtain mainshock only [12–15]. All parameters showed in Table 2 and 3.

2.2. Probabilistic Seismic Hazard Analysis/PSHA
The essence of PSHA calculated the probabilistic of distance, magnitude and exceeding chance of certain acceleration. To fulfil the parameters, coordinate earthquake, location and attenuation are needed. Attenuation is weakening shaking mechanism as the function of distance and magnitude based on earthquake type. According to the previous chapter, Java Island modelled using two mechanisms, i.e., shallow crustal and subduction. During simulation, the attenuation function provided by database software. Thus, in this paper, attenuation function used are: Bore - Atkinson (2007) NGA USGS 2007, Campbell - Bozorgnia (2007) NGA USGS 2007 and Chiou - Youngs (2008) NGA USGS 2008 for shallow crustal mechanism and Zao et.al (2006) USGS 2008, Atkinson - Bore (2003) Worldwide Subduction USGS 2008, Young et.al (1997) Subduction Rock for subduction mechanism.

2.3. Disaggregation
The aim of this phase is knowing which mechanism that dominate in the study area. By doing this step, correct and appropriate attenuation function will become more realistic than if not doing this one. Attenuation function will be used to obtain response spectra then later will be matching by PSHA one.

2.4. Wave Propagation (Arias Intensity and Amplification)
In wave propagation step, the ground motion will be propagated from bedrock to surface with the limitation of basin effect is neglected and applied method is Damped Equivalent Linear with Elastic Bedrock Method. For soil parameter, some assumption due to deficiency of data, i.e., Seed and Idris (1970) means area backbone curve applied on sand soil also Vucetic and Dorby (1991) backbone curve applied on fine soil using specific PI [4]. Velocity shear (Vs) using N-SPT correlation using method proposed by Dikmen [16]. During this phase, DeepSoil software conducted for the analysis to obtain amplification and effective time from arias intensity. Arias intensity is a method that proposed by Arturo Arias in 1970 to knowing acceleration function and time for specific needs [17,18]. On the other hand, amplification is a process of earthquake parameter amplify which in this study focused on ratio surface and bedrock acceleration.

| Structure                  | Segment            | L (km) | W (km) | M  | b-val | a-val |
|----------------------------|--------------------|--------|--------|----|-------|-------|
| Sumatran Megathrust        | Sunda Strait       | 290    | 100    | 8.7| 1.15  | 5.99  |
| Sunda Megathrust           | West-Central Java | 700    | 150    | 8.7| 1.08  | 5.55  |
| Sunda Megathrust           | East Java          | 280    | 150    | 8.7| 1.08  | 5.63  |
Table 3. Shallow Crustal earthquake source. [11]

| Segment/Main(*) | Type             | Dip | L (km) | Slip rate (mm/year) | M Max |
|-----------------|------------------|-----|--------|---------------------|-------|
| Cimandiri       | Reverse Slip     | 45S | 23     | 0.55                | 6.7   |
| Nyalindung-Cibeber | Reverse Slip  | 45S | 30     | 0.55                | 6.5   |
| Rajamandala     | Strike-Slip      | 90  | 45     | 0.4                 | 6.6   |
| Lembang         | Strike-Slip      | 90  | 29.5   | 0.1                 | 6.8   |
| Subang          | Reverse Slip     | 45S | 33     | 2                   | 6.5   |
| Cirebon-1       | Reverse Slip     | 45S | 15     | 0.1                 | 6.5   |
| Cirebon-2       | Reverse Slip     | 45S | 18     | 0.1                 | 6.5   |
| Karang Malang   | Reverse Slip     | 45S | 22     | 0.1                 | 6.5   |
| Brebes          | Reverse Slip     | 45S | 22     | 0.1                 | 6.5   |
| Tegal           | Reverse Slip     | 45S | 15     | 0.1                 | 6.5   |
| Pekalongan      | Reverse Slip     | 45S | 16     | 0.1                 | 6.5   |
| Welgeri         | Reverse Slip     | 45S | 17     | 0.1                 | 6.5   |
| Semarang        | Reverse Slip     | 45S | 34     | 0.1                 | 6.5   |
| Rawapeningen    | Reverse Slip     | 45S | 18     | 0.1                 | 6.5   |
| Demak           | Reverse Slip     | 45S | 31     | 0.1                 | 6.5   |
| Purwodadi       | Reverse Slip     | 45S | 38     | 0.1                 | 6.5   |
| Cepu            | Reverse Slip     | 45S | 100    | 0.1                 | 6.5   |
| Waru            | Reverse Slip     | 45S | 64     | 0.05                | 6.5   |
| Surabaya        | Reverse Slip     | 45S | 25     | 0.05                | 6.5   |
| Blumbang        | Reverse Slip     | 45S | 31     | 0.05                | 6.6   |
| Ciremai*        | Strike-slip      | 90  | 20     | 0.1                 | 6.5   |
| Ajibarang*      | Strike-slip      | 90  | 20     | 0.1                 | 6.5   |
| Opak*           | Strike-slip      | 60E | 45     | 0.1                 | 6.6   |
| Merapi-Merbabu* | Strike-slip      | 90  | 28     | 0.1                 | 6.6   |
| Pati Thrust*    | Strike-slip      | 90  | 69     | 0.1                 | 6.5   |

3. Result and Discussion

PSHA in Yogyakarta Special Region from this study show that peak ground acceleration agrees with the conclusion of PGA at bedrock in PE 2% for 50 years (Figure 2) from PusGen, i.e., the range of 0.5-0.6g [11]. From disaggregation, it reveals that dominating earthquake source is Opak Fault which included in shallow crustal attenuation function. This phenomenon showed in Figure 3 where the dominant hazard value is $4.10^4$ with the range of 0.55 amplitude at BH-01, 02 dan 04 that belong to Opak Fault properties.

![Figure 2](image-url)
Figure 3. Example of disaggregation for location BH-01 (a) and Hazard Curve (b).

PSHA response spectra later matched by disaggregation with ground motion database that already available in DeepSoil database to obtain synthetic ground motion. In this study, there are three selected similar ground motion, i.e., Cape Mendocino, Loma Prieta and Victoria which all of them are fault mechanism. These ground motion have a maximum acceleration in the range 0.5-0.6g (Figure 4).

Figure 4. Time histories of Cape Mendocino (a), Loma Prieta (b) and Victoria (c) ground motion.

These synthetic ground motion later applied each beneath of bedrock site study. After that, acceleration amplification and effective time of Arias intensity (tₐ₋₉₅) observed. Effective time of Arias intensity is a time parameter that has dominant influence where earthquake wave transfer its energy as mentioned by Trifunac and Brady. Here the amplification in wave propagation graph at BH-01, BH-02 and BH-04 and sample method to obtain tₐ at BH-01 using Cape Mendocino ground motion (Figure 5). Summarize of natural frequency, amplification, effective delta time on each site also shown in Table 4.
Figure 5. (a, b, c) Amplification each site and (d) example of bedrock arias intensity effective time at BH-01

From Figure 5, it showed that time effective of ground motion is a delta between a time of 95% and 5%. Thus, from this study, it can be observed the correlation between amplification, time effective arias intensity, and condition of each location. Cape Mendocino and Loma Prieta ground motion always seem to make the highest amplification in all site except for BH-04, since Victoria ones slightly higher than Loma Prieta ones. Natural frequency (f site) correlates with the stiffness of the site itself. Higher natural frequency, smaller amplification. This phenomenon occurred because of natural frequency linear with the shear velocity of soil.

Table 4. Summarize all site.

| ID    | Ground motion | t5-95 (s) | f site (Hz) | Acceleration Amplification |
|-------|---------------|-----------|-------------|----------------------------|
|       |               | Bedrock   | Surface     |                            |
| BH-01 | Cape Mendocino| 12.08     | 14.1        | 2.315                      |
|       | Loma Prieta   | 9.42      | 10.04       | 2.320                      |
|       | Victoria      | 9.28      | 7.92        | 1.859                      |
| BH-02 | Cape Mendocino| 10.8      | 14.1        | 1.978                      |
|       | Loma Prieta   | 7.52      | 10.04       | 3.136                      |
|       | Victoria      | 22.14     | 9.18        | 2.235                      |
| BH-04 | Cape Mendocino| 17.44     | 13.4        | 2.672                      |
|       | Loma Prieta   | 11.8      | 9.32        | 1.896                      |
|       | Victoria      | 6.36      | 8.96        | 1.690                      |

4. Conclusion
The results of this study can be drawn as follow: the higher natural frequency at the site the lesser amplification developed. The highest amplification takes place at BH-04 which has the smallest natural frequency. Moreover, the smallest one occurred at BH-02 with highest natural frequency. There is a tendency that the smaller delta effective time arias intensity, the more significant amplification occurred except for Loma Prieta ground motion.
5. References

[1] Elnashai A S Kim S J Yun G J and Sidarta D 2007 The Yogyakarta Earthquake of May 27, 2006 MAE Center CD Release 07-02

[2] Newcomb K R and McCann W R 1987 Seismic history and seismotectonics of the Sunda Arc *Journal of Geophysical Research: Solid Earth* 92 B1 421–439

[3] Mignan A King G Bowman D Lacassin R and Dmowska R 2006 Seismic activity in the Sumatra–Java region prior to the December 26, 2004 (Mw= 9.0–9.3) and March 28, 2005 (Mw= 8.7) earthquakes *Earth and Planetary Science Letters* 244 3–4 639–654

[4] Hashash Y M A Musgrove M I Harmon J A Ilhan O Groholski D R Phillips C A and Park D 2017 DEEPSOIL 7.0, User Manual

[5] Syahbana A J and Iqbal P 2014 Perbandingan pemodelan respon spektra menggunakan analisis discreet point dengan standar perencanaan ketahanan gempa untuk bangunan gedung dan non gedung tahun 2010 (Studi kasus Kecamatan Cilacap Selatan, Kota Cilacap, Provinsi Jawa Tengah) *Jurnal Lingkungan dan Bencana Geologi* 5 2 129–142

[6] Davies R J Brumm M Manga M Rubiandini R Swarbrick R and Tingay M 2008 The East Java mud volcano (2006 to present): an earthquake or drilling trigger? *Earth and Planetary Science Letters* 272 3–4 627–638

[7] Burton P W Weatherill G Karnawati D and Pramumijoyo S 2008 Seismic hazard assessment and zoning in Java: New and alternative probabilistic assessment models *International Conference on Earthquake Engineering and Disaster Mitigation* 2008 2291–2834

[8] Patton J R Goldfinger C and Djadjadidhardja Y 2013 Slope stability: Factor of safety along the seismically active continental slope offshore Sumatra *AGU Fall Meeting Abstracts*

[9] Rahardjo W Sukandarrumidi and Rosidi H M D 1977 Peta Geologi Lembar Yogyakarta (Java: Direktorat Geologi)

[10] Brotopuspito K S Prasetya T and Widigdo F M 2006 Percepatan Getaran Tanah Maksimum Daerah Istimewa Yogyakarta 1943-2006 *Geofisika* 7 1 19–22

[11] PusGen 2017 *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017 1st ed.* (Bandung: Puslitbang Perumahan dan Pemukiman)

[12] Vipin K S Anbazhagan P and Sitharam T G 2009 Estimation of peak ground acceleration and spectral acceleration for South India with local site effects: probabilistic approach *Natural Hazards and Earth System Sciences* 9 3 865

[13] Stucchi M Albini P Mirto M and Rebez A 2004 Assessing the completeness of Italian historical earthquake data *Annals of Geophysics* 47 2–3 2

[14] Stepp J C 1972 Analysis of completeness of the earthquake sample in the Puget Sound area and its effect on statistical estimates of earthquake hazard *Proc. of the 1st Int. Conf. on Microzonazion, Seattle* 2 897–910

[15] Weichert D H 1980 Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes *Bulletin of the Seismological Society of America* 70 4 1106–1337

[16] Dikmen Ü 2009 Statistical correlations of shear wave velocity and penetration resistance for soils *Journal of Geophysics and Engineering* 6 1 61

[17] Arias A 1970 MEASURE OF EARTHQUAKE INTENSITY., Massachusetts Inst. of Tech., Cambridge. Univ. of Chile, Santiago de Chile

[18] Rezaeian S and Der Kiureghian A 2012 Simulation of orthogonal horizontal ground motion components for specified earthquake and site characteristics *Earthquake Engineering & Structural Dynamics* 41 2 335–353