Preliminary spectral matching analysis of RDE site at Serpong Indonesia

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Abstract. In concurrent with the plan to build small experimental power reactor at Serpong site, site specific response spectra evaluation is required to ensure the reactor safety. Site response spectra involved the spectral matching analysis which incorporates the seismic characteristics of the site and the design spectra. This paper presented the preliminary spectral matching analysis of selected natural earthquake records by comparing Al Atik & Abrahamson (2006) algorithm and Hancock et. al (2010) algorithm. The natural earthquake records were selected based on their similarity of their characteristics such as magnitude, distance resulting from deaggregation analysis and site-specific conditions. Two subset periods were employed in the spectral matching analysis. Fourier spectrum and wave envelope analysis showed that both algorithms have maintained the original non-stationary characteristics. PGA, PGV and PGD values resulting from spectral matching have significant changes from the original as an implication of accelerogram amplitude scaling. From the spectral matching analysis, KAU083 record resulting from Hancock et. al (2006) algorithm has yielded the best matched to the target spectra compared to other selected records.

1. Introduction

By considering the geographical characteristics of Indonesia, small nuclear reactor potentially feasible to be further developed. To initiate that, a plan to build a small experimental power reactor called Reaktor Daya Eksperimental (RDE) is currently in progress. RDE is a pebble bed type high temperature gas reactor which was chosen due to its strong passive safety feature[1]. Despite the strong passive safety feature possess by RDE, it is of importance to ensure reactor safety especially from earthquake hazard. Incorporating earthquake hazard into reactor civil design is conducted through the site specific response spectra evaluation.

Site specific response spectra evaluation involves the Probabilistic Seismic Hazard Analysis (PSHA), deaggregation analysis, input motion selection, spectral matching, site response spectra at bedrock level and finally the propagation of seismic wave from bedrock to foundation level. Deaggregation analysis of seismic hazard is a process to determine dominant earthquake magnitude (M) and distance (R) from PSHA result which pose the largest effect to the site at certain earthquake return period[2]. Deaggregation analysis data used in this paper was secondary data which have been resulted from
previous study as part of RDE’s site evaluation back in 2016. This study was performed by The National Nuclear Energy Agency (BATAN) in corporation with the agency of Meteorology, Climatology and Geophysics (BMKG).

Input motion or rock motion selection synchronizes the site characteristics with certain seismic wave event. Selecting seismic input is seen to be one of the most critical in the seismic assessment of structures via non-linear dynamic analysis and sometimes considered more important than structural modeling[3]. As quoted from Bray and Travasarou (2007), Athanasopoulos (2008), and Rathje et al. (2010) the selection process of ground motion can have a large effect on the goodness of fit of a spectral matching process. Failure to select the appropriate input motion could lead to a false site specific spectra and eventually risking the building design itself.

According to Boomer and Acevedo (2004), quoted from Iervolino (2008), “the signals that can be used for the seismic structural analysis consists of artificial waveforms, simulated accelerograms and natural records”[4][3]. Ground motion data sparseness, sometime leads some researcher to generate artificial time series. Ostadan (1996) performed the evaluation of input motion characteristic based on phase angles and strong motion duration[5]. But above all, natural records regards as the best option as input signals to produce site specific response spectra[3]. For that reason, this paper used the input motion from natural earthquake records acquired from PEER Ground Motion Database.

Rather than selecting records only based on the magnitude and distance, spectral matching was conducted to each of the selected records using Uniform Hazard Spectra (UHS) of RDE site as the target spectra. Spectral matching was performed using SEISOMATCH 2018 software. SEISOMATCH considered as a powerful tool to conduct spectral matching while maintaining the non-stationary characteristics of the original records. It provides two defaults algorithm, namely Al Atik Abrahamson (2010) algorithm and Hancock (2006) algorithm.

This paper’s objective is to perform preliminary spectral matching analysis of selected natural earthquake records by comparing Al Atik & Abrahamson (2010) algorithm[6] and Hancock (2006) algorithm[7]. The resulting time history from these two algorithms were compared based on the spectral misfit value. The expected result is a time history data which strongly represent the seismic and geological characteristics of the site. The matched time histories could be further used for the calculation of Peak Ground Acceleration (PGA) at foundation level which strongly important for the RDE civil design.

In the following discussions, the soil characteristics of RDE site based on borehole test are reviewed first. Subsequently the methods and criteria used for screening real ground motions are explained completed with the spectral matching tool used in this paper. Finally, the results from screening and spectral matching analysis are discussed.

2. Soil Characteristics of RDE’s Site

In order to understand the site-specific response at the ground or foundation level, the rock and soil characteristics of the site should have been known first. Rocks and soil characteristics are dominant factors which influence the ground response during an earthquake event. For this specific reason, geotechnical boring and coring has been performed at 26 boreholes confined the RDE site.

Based on the geological and geotechnical data acquired, RDE site lies on Serpong Fm, which comprise of clay, clayey to silt, loose to medium gravel and dense gravel, and Bojongmanik Fm which consist of sandy claystone, clayey sandstone and darker grey sandy claystone. Soil analysis was conducted for at least 10 meters depth.

Table 1 shows the soil characteristics based on DH-11 borehole which is located at the center of proposed reactor building.

Shear wave velocity (Vs) data was gained by using seismic cross-hole test. The seismic cross-hole was performed up to 100 meters with measurement interval of 1 meter. According to the shear wave profile, clay, sand and gravel at less than 20 m depth has Vs of about 150 – 250 m/s. In classifying a site, all soil and rock layers in the upper 100 feet (~30 m) of the site profile are considered[8]. Based on
the cross-hole test, the average Vs30 of RDE site is 285 m/s. Thus, referring to the site class definition from ASCE 7-02 and ASCE 7-05[8], the RDE site is classified as site class D.

Table 1. Soil Characteristics based on DH-11 borehole.

| Depth (meters) | Material Description                  | SPT |
|---------------|--------------------------------------|-----|
| 0 – 2         | Clay to silt                         | 12  |
| 2 – 3         | Clayey to silty sand, yellowbrown    | 12  |
| 3 – 6         | Silty to claysed sand, light brown   | 17  |
| 6 – 9         | Silty to claysed sand, light brown   | 39  |
| 9 – 12        | Silty to claysed sand, light brown   | 41  |
| 12.00 – 15.00 | Silty to claysed sand, light brown   | 54  |
| 15.00 - 18.00 | Silty to claysed sand, light brown   | 37  |
| 18.00 – 21.00 | Sandy claystone 3                    | 53  |
| 21 – 24       | Sandy claystone 3                    | 30  |
| 24 - 27       | Sandy claystone 3                    | 37  |

3. Methodology

Deaggregation analysis of RDE site has revealed that the earthquake mean magnitude and distance was respectively 7.88 and 122.28 km[9]. The analysis was carried out using 5% damping within 1000 years return period. The seismotectonic model suggested that the yielded mean magnitude and distance are resulted from subduction zone of Java Megathrust. As mentioned in the previous chapter, UHS at RDE site bedrock was used as the target spectra. This acceleration spectrum was produced from the PSHA calculation at the site with 5% damping and 1000 years return period by using the same earthquake parameter and database as used when performing deaggregation analysis.

According to USACE (1999) there are two methods that can be used to select earthquake acceleration time-histories at bedrock either by utilizing existing ground motion time histories recorded near the site or by generating artificial ground motions time histories[10]. The selection of rock input motions has to consider certain variables such as magnitude, source distance, faults and source mechanism[11]. Site characteristics represented by the site class category is also one of the parameters to be considered when choosing the right input motion. The time histories data are acquired from the Pacific Earthquake Engineering Research Center (PEER) Ground Motion Database available at the website http://ngawest2.berkeley.edu. The downloaded strong motion data were unscaled and as-recorded displacement, velocity and acceleration trace files.

The actual ground motions from worldwide earthquakes are selected based on their similarity of their characteristics such as magnitude, distance and site conditions[10]. However, a number of points arise regarding the criteria for appropriate selection and manipulation of such records[3]. Elnashai & Sarno (2008) suggested using searching criteria within a range of ± 0.3 magnitude unit and ± 20-40 km distance. Thus, we set the preliminary input motion selection criteria as shown in Table 2. Elnashai also explain that matching magnitude is more important than matching the distance.

Table 2. Records selection criteria.

| Magnitude          | Distance (Rrup) | Fault Mechanism    | Site Class |
|--------------------|----------------|-------------------|------------|
| 7.88 ± 0.3         | 122.28 ± 20 km | Reverse/Normal    | D          |

The basic principle of spectral matching is to seek a modified signal with an excellent match to the target spectrum, while maintaining the original seed signal’s nonstationary statistics, such as general envelope, time location of large pulses, and variation of frequency content with time[12].
Spectral matching analysis was performed to the selected records using SEISMOMATCH 2018. SEISMOMATCH performed the spectral matching analysis on time domain using wavelets adjustment using either Al Atik and Abrahamson (2010) or Hancock (2006) algorithm. Both algorithms was established based on the original wavelet of Lilhanand and Tseng (1987, 1988)[6][7]. Hancock et. al (2006) algorithms was developed to eliminate velocity and displacement drift resulted from the previous Abrahamson (1992) algorithm[6]. Al Atik & Abrahamson (2010) was then proposed another algorithm to ensure stability, efficiency and speed of numerical solution and also prevents drift in the resulting velocity and displacement time series[6]. In principle, Hancock (2006) and Al Atik & Abrahamson (2010) have a quite different wavelet applied to the algorithm. Hancock (2006) used corrected tapered cosine wavelet (see Equation 1) while Al Atik & Abrahamson (2010) applied an improved tapered cosine wavelet (see Equation 2) in order to fit with the target spectra.

Each of the selected record was matched twice using different subset periods. Initial matching was iterated through the period of 0.05 sec up to 2 sec. Subsequently, the accelerogram matched resulted from the initial matching was then have another matching process through the minimum period of 0.05 sec and maximum period of 4 sec. As explained in Al Atik & Abrahamson (2006), this method is chosen because short period spectral acceleration is influenced by long period wavelets, only the short period range of the response spectrum is matched in the first pass. The spectral misfit which consist of average and maximum misfit resulting from the iteration process were used as the basis for selecting the input motion. Spectral misfit as mentioned in Adekristi (2013) is defined as the difference between the target spectrum ordinate and the ground motion spectrum ordinate at a given period and one particular damping ratio[13].

The matching parameters when using both the Al-Atik and Abrahamson algorithm and Hancock Algorithm were principally the same. For instance, the mismatch tolerance was set at 0.3 (maximum default provided for academic license type) with the maximum iteration number of 50 and the group size of 250. Hancock algorithm required more parameters to be set-up, such as the alpha model parameter and PGA correction parameters, but for practical reason, it was all set to default numbers.

4. Result and Discussion
Based on the preliminary selection criteria shown in Table 2, there are 27 strong motion records which all been yielded from the 1999 ChiChi earthquake event in Taiwan with the magnitude of 7.62 and the fault mechanism is reverse oblique (Table 3). These records were coming from different recording stations.

Table 4 displays a summary comparison of the Al Atik & Abrahamson (2010) and Hancock (2006) algorithm using the method described in the previous chapter. It clearly shows that for most accelerograms, the Hancock (2006) algorithm provides a smaller average misfit and requires less iterations number to achieved convergent result compare to Al Atik & Abrahamson (2010) algorithm. The mean misfit for 27 records using Hancock algorithm is 3.84% while Al Atik & Abrahamson algorithm gives a mean misfit of 4.49%. The mean maximum misfit for Hancock is around 24.11%, while Al Atik & Abrahamson is 25.82%.

SEISMOMATCH perform the spectral matching analysis in time domain. Time domain method is considered as a better approach rather than performing spectral matching in frequency domain. This method adjusts the original accelerogram in the time domain by adding wavelets. Al-Atik and Abrahamson (2006) algorithm used an improved tapered cosine wavelet to prevent velocity and displacement drift.

As mentioned in previous chapter, according to Alexander et. al (2014), there were three criteria to ensure that the spectral matching has preserved the non-stationary characteristics of the original accelerogram. First is the general envelope of the overall accelerogram. By using the records from KAU083, both Al Atik & Abrahamson (2010) and Hancock (2010) algorithm has successfully reserved the general envelope of the matched accelerogram compare to original accelerogram as shown in Figure 1. The wave envelope is developed using Hilbert transform function in MATLAB.
Table 3. List of strong motion records.

| Station Name | Magnitude | Mechanism          | Rjb (km) | Rrup (km) | Vs30 (m/sec) |
|--------------|-----------|--------------------|----------|-----------|--------------|
| KAU006       | 7.62      | Reverse Oblique    | 113.37   | 114.92    | 218.49       |
| KAU007       | 7.62      | Reverse Oblique    | 105.92   | 107.57    | 290.86       |
| KAU008       | 7.62      | Reverse Oblique    | 107.02   | 108.75    | 285.94       |
| KAU015       | 7.62      | Reverse Oblique    | 106.51   | 107.97    | 233.21       |
| KAU030       | 7.62      | Reverse Oblique    | 100.12   | 102.09    | 259.36       |
| KAU032       | 7.62      | Reverse Oblique    | 111.02   | 112.81    | 194.13       |
| KAU033       | 7.62      | Reverse Oblique    | 119.31   | 120.97    | 182.93       |
| KAU037       | 7.62      | Reverse Oblique    | 135      | 136.47    | 283.21       |
| KAU044       | 7.62      | Reverse Oblique    | 119.96   | 121.61    | 221.24       |
| KAU058       | 7.62      | Reverse Oblique    | 107.77   | 109.17    | 229.66       |
| KAU062       | 7.62      | Reverse Oblique    | 112.23   | 113.46    | 246.84       |
| KAU073       | 7.62      | Reverse Oblique    | 108.84   | 110.67    | 216.33       |
| KAU074       | 7.62      | Reverse Oblique    | 103.68   | 105.59    | 228.34       |
| KAU075       | 7.62      | Reverse Oblique    | 114.84   | 116.57    | 196.3        |
| KAU083       | 7.62      | Reverse Oblique    | 109.14   | 110.95    | 202.14       |
| KAU087       | 7.62      | Reverse Oblique    | 111.67   | 113.13    | 276.11       |
| KAU088       | 7.62      | Reverse Oblique    | 108.91   | 110.22    | 227.46       |
| TAP003       | 7.62      | Reverse Oblique    | 101.27   | 102.39    | 212.39       |
| TAP006       | 7.62      | Reverse Oblique    | 104.16   | 105.66    | 184.77       |
| TAP007       | 7.62      | Reverse Oblique    | 102.16   | 103.73    | 207.39       |
| TAP008       | 7.62      | Reverse Oblique    | 102.84   | 104.52    | 194.14       |
| TAP013       | 7.62      | Reverse Oblique    | 100.84   | 102.59    | 205.11       |
| TAP014       | 7.62      | Reverse Oblique    | 101.63   | 103.45    | 188.98       |
| TAP041       | 7.62      | Reverse Oblique    | 110.28   | 110.9     | 363.56       |
| TAP084       | 7.62      | Reverse Oblique    | 122.13   | 123.71    | 224.22       |
| TAP090       | 7.62      | Reverse Oblique    | 103.65   | 105.56    | 324.38       |
| TAP095       | 7.62      | Reverse Oblique    | 107.8    | 109       | 206.24       |

Figure 1. KAU083 wave envelope comparison between original, Al Atik & Abrahamson (2006) and Hancock (2010).
Table 4. Summary Comparison of Result from Al Atik & Abrahamson (2010) and Hancock (2006) algorithm.

| Accelerogram | Al Atik & Abrahamson (2010) | Hancock (2006) |
|--------------|-------------------------------|----------------|
|              | Ave. Misfit | Max. Misfit | Iteration | Max. Acc. | Ave. Misfit | Max. Misfit | Iterations | Max. Acc. |
| KAU06.txt    | 5.90%       | 25.20%   | 22        | 0.68499 g | 3.80%       | 24.80%   | 5          | 0.68541 g |
| KAU07.txt    | 4.40%       | 28.00%   | 21        | 0.68519 g | 5.30%       | 25.00%   | 4          | 0.68776 g |
| KAU08.txt    | 3.70%       | 28.20%   | 18        | 0.68499 g | 2.00%       | 15.90%   | 8          | 0.68533 g |
| KAU015.txt   | 5.50%       | 28.70%   | 13        | 0.68477 g | 2.90%       | 24.60%   | 4          | 0.68415 g |
| KAU030.txt   | 5.30%       | 28.00%   | 13        | 0.68482 g | 3.40%       | 23.40%   | 8          | 0.68518 g |
| KAU032.txt   | 3.80%       | 21.90%   | 20        | 0.68442 g | 1.80%       | 22.80%   | 7          | 0.68471 g |
| KAU033.txt   | 2.70%       | 29.10%   | 34        | 0.68279 g | 6.80%       | 24.10%   | 4          | 0.68586 g |
| KAU037.txt   | 7.20%       | 28.20%   | 18        | 0.68499 g | 2.00%       | 15.90%   | 11         | 0.68495 g |
| KAU044.txt   | 3.50%       | 25.60%   | 16        | 0.68517 g | 2.90%       | 22.20%   | 8          | 0.68569 g |
| KAU058.txt   | 5.80%       | 26.70%   | 21        | 0.71549 g | 5.20%       | 23.90%   | 7          | 0.68331 g |
| KAU062.txt   | 3.90%       | 24.40%   | 18        | 0.68509 g | 3.30%       | 24.70%   | 9          | 0.68607 g |
| KAU073.txt   | 5.20%       | 22.70%   | 19        | 0.68487 g | 2.00%       | 24.70%   | 9          | 0.68459 g |
| KAU074.txt   | 4.20%       | 29.40%   | 14        | 0.68584 g | 3.20%       | 22.70%   | 7          | 0.68453 g |
| KAU075.txt   | 2.90%       | 25.90%   | 19        | 0.68485 g | 3.20%       | 20.80%   | 6          | 0.68644 g |
| KAU083.txt   | 2.60%       | 24.90%   | 24        | 0.68517 g | 1.20%       | 19.80%   | 7          | 0.68531 g |
| KAU087.txt   | 5.20%       | 27.90%   | 27        | 0.71634 g | 6.70%       | 27.50%   | 4          | 0.68214 g |
| TAP003.txt   | 4.80%       | 20.30%   | 20        | 0.68531 g | 5.10%       | 29.00%   | 2          | 0.69676 g |
| TAP006.txt   | 3.40%       | 22.90%   | 8         | 0.68906 g | 7.40%       | 28.00%   | 3          | 0.70214 g |
| TAP007.txt   | 2.70%       | 21.90%   | 17        | 0.68966 g | 4.10%       | 29.60%   | 5          | 0.68589 g |
| TAP008.txt   | 4.20%       | 25.50%   | 11        | 0.68457 g | 3.10%       | 21.40%   | 3          | 0.68965 g |
| TAP013.txt   | 6.80%       | 27.40%   | 16        | 0.68531 g | 3.60%       | 21.60%   | 3          | 0.68784 g |
| TAP014.txt   | 2.90%       | 23.60%   | 17        | 0.68507 g | 5.20%       | 26.20%   | 2          | 0.68904 g |
| TAP041.txt   | 5.90%       | 27.10%   | 12        | 0.68650 g | 3.00%       | 17.30%   | 3          | 0.68562 g |
| TAP084.txt   | 6.90%       | 28.10%   | 4         | 0.68515 g | 3.20%       | 27.00%   | 10         | 0.68517 g |
| TAP090.txt   | 2.90%       | 29.00%   | 6         | 0.82856 g | 6.80%       | 29.50%   | 3          | 0.68517 g |
| TAP095.txt   | 3.60%       | 20.30%   | 13        | 0.68680 g | 3.00%       | 29.20%   | 4          | 0.68771 g |

Figure 2 displays the Fourier spectra of KAU records. It clearly shows that the original earthquake records are scaled in terms of amplitude to match-up the target spectra by preserving the frequency content of original accelerogram. Al Atik & Abrahamson (2010) algorithm gives a more stable amplitude to the original rather than Hancock (2006) algorithm.

The third criterion for spectral matching is related to the time location of large pulses. If the assumption is that the large pulses are represented by the maximum acceleration, then time location for the large pulses could be identified. Evaluation to the original and matched time histories of KAU083 record (Figure 3), gives a slightly different time location of 0.4 sec for large pulses from the original time histories. This might due to the phase drift identified from the spectral matching process. From the evaluation, it shows that the average phase difference from the original and matched time histories is
0.17° with a maximum difference of ±6.2°. This slight drift is considered as a reasonable drift due to the usage of as-recorded and un-scaled records.

![Figure 2](image1.png)

**Figure 2.** Fourier Spectra comparison of KAU083 records (a) Al Atik & Abrahamson (b) Hancock.

![Figure 3](image2.png)

**Figure 3.** Time series comparison original vs matched of KAU83 records (a) Al Atik & Abrahamson, (b) Hancock.
PGA, PGV and PGD comparison for both algorithms are presented in Table 5. These three parameters are expected to scale-up along with the accelerogram amplitude scaling-up as explained previously. PGA changed is around ten times compare to the original records which we can see it has a linear pattern. In terms of PGA and PGD, Al Atik & Abrahamson (2010) algorithm gives a more significant changes rather than Hancock (2006) algorithm.

|                | Original  | Al Atik & Abrahamson (2010) | Hancock (2006) |
|----------------|-----------|-----------------------------|-----------------|
| PGA (g)        | 0.02862   | 0.23822                     | 0.28576         |
| PGV (cm/sec)   | 8.84747   | 70.75546                    | 40.25624        |
| PGD (cm)       | 7.63698   | 119.72547                   | 12.66184        |

Figure 4. KA083 records response spectra comparison: Al Atik & Abrahamson (2010) algorithm (Left) and Hancock (2006) algorithm (Right).

Figure 4 displays the response spectra comparison between the two algorithms used in this paper. Mean matched spectrum resulted from Hancock (2006) algorithm provides a better matched throughout the period of 0.001 sec to 4 sec with the average misfit of 1.20% and maximum misfit of 19.80% as shown in Table 4. The Al Atik & Abrahamson (2010) algorithm results a bigger misfit of mean matched spectrum with average misfit of 2.60% and maximum misfit of 24.90%. It is clearly shown in Figure 4 that the mean matched spectrum has a little bit of spike at the period between 2.5 sec and 3 sec. Thus, in summary, by considering the average misfit value of both algorithms and spectral shape, KAU083 records from Hancock et. al (2006) algorithm has the best matched spectrum compare to other selected records.

5. Conclusion

Strong motion database from PEER database was used to acquire seed records. Records selection criteria were based on the deaggregation analysis result, the soil characteristics at the site, and fault mechanism. In order to acquire the best fit input motion for seismic hazard analysis at the site, spectral matching was performed using SEISOMATCH 2018. Two algorithms were employed for spectral matching analysis, namely Al Atik & Abrahamson (2010) and Hancock (2006) algorithm. Uniform Hazard Spectra of the site for 1000 years return period earthquake was used as the target spectra. Fourier spectrum and wave envelope analysis showed that both algorithms have maintained the original non-stationary characteristics. PGA, PGV and PGD values resulting from spectral matching have significant changes from the original as an implication of accelerogram amplitude scaling. From the spectral matching analysis, KAU083 record resulting from Hancock et. al (2006) algorithm has yielded the best matched to the target spectra compare to other selected records.
Acknowledgements

Funding for this research was provided by the Ministry of Research, Technology and Higher Education under grant of Insentif Riset Sistem Inovasi Nasional number 01/INS-1/PPK/E4/2018. This support is gratefully acknowledged. We are also thankful to BMKG and PTBGN-BATAN for providing necessary data and analysis.

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