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COMPARISON OF BEDROCK AND SURFACE TIME HISTORIES SUBJECTED TO SUBDUCTION EARTHQUAKES IN A SELECTED LOCATION OF YOGYAKARTA

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ABSTRACT: In practical building design, a time history is usually based on earthquake records from somewhere else, without any precise matching processes. Consequently, the time history is rarely used in building analysis, because of the difficulty in collecting accurate data at the building site. In this study, the site of the Alana Yogyakarta Hotel was selected as a research object for determining the real-time history, aimed towards an earthquake hazard analysis by using the Probabilistic Seismic Hazard Analysis (PSHA) method. Earthquake events affecting Yogyakarta and its surrounding areas were collected from earthquake catalogs and they were supplied from various sources, either from the government and/or from international institutions. The data that was used in the hazard analysis was focused on the main shock only, so the separation processes were essentially required to distinguish between the main shock, the foreshock and the aftershock. Due to the unavailability of attenuation functions, these were then determined based upon the earthquake data, by selecting the similarities of the tectonic and geological conditions in Indonesia, thus producing a seismic hazard curve and a uniform hazard response spectrum. The time history data on the bedrock was selected based on the dominant magnitude and the dominant distance of the subduction earthquakes and matched with the uniform hazard response spectrum, so as to produce a matched response spectrum. The results have shown that the peak times of the acceleration increased, as the results of the matching earthquake data on the bedrock corresponded to the hazard deaggregation analysis.

Keywords: Time history, Subduction earthquake, Hazard deaggregation analysis, Bedrock, Surface

1. INTRODUCTION

Indonesia is traversed by the meeting point of three major tectonic plates, the Indo-Australian Plate, the Eurasian Plate and the Pacific Plate, as well as with a microplate of the Philippines [1]. These tectonic processes form seismic zones in the forms of subduction, translational and thrust zones in most parts of Indonesia. All of these zones are characterized by a shift in the earth's crust, which almost always creates tectonic earthquakes [2]. Based on these seismotectonic conditions, Indonesia is an area prone to earthquake disasters.

An earthquake is a natural event that until now cannot be predicted as to when and where it will happen. It can cause a large loss of properties, together with many human casualties. An earthquake is a vibration of the soil's surface, due to the sudden release of energy, resulting from the breaking up of the rock masses in the crust layers [3]. Earthquakes frequently happen as a resulting cause of tectonic plate movements, which are often called tectonic earthquakes. Up until now, an earthquake is a disaster that cannot be prevented and it cannot be accurately predicted, either by time, the place of occurrence, or its magnitude. Thus, an earthquake disaster has the potential of causing serious problems, because it may induce much damage and create large losses. Experts can only predict the possibility of earthquakes, based on scientific research and by identifying areas that are at risk of earthquake hazards [3]. The intensity of earthquakes in Indonesia has been overwhelming during the last 50 years, as presented in Fig. 1. In recent years, there have been many significant and devastating earthquakes in Indonesia, including the 2004 Aceh (9.3 SR), the Nias–Simeulue 2005 (8.7 SR), the Bantul 2006 (6.3 SR), the Bengkulu 2007 (7.9 SR), the Papua 2009 (7.6 SR) and the Padang 2009 (7.6 SR).

Yogyakarta has experienced moderate to high seismic activities. Based upon the historical data of earthquakes, several destructive earthquakes have occurred in this region, one of which was the Yogyakarta earthquake on 27 May 2006, which resulted in damage to infrastructures and killed thousands of people. The quake had a strength of 6.3 SR, with its epicenter located at 7.962 LS and 110.458 BT (East of the Opak River), at a depth of 10 km [4]. This condition shows that the Special Region of Yogyakarta has a high vulnerability to earthquake disasters, while it also has a relatively large population, thus causing a high level of risk to human lives.

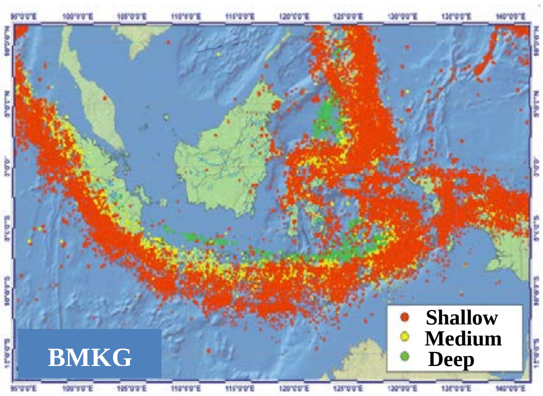

Fig. 1 Map of seismicity in Indonesia for the period 1971-2010 [5]

Building planning and design work in earthquake-prone areas must take into account the quantitative earthquake hazards, by considering the seismological, geological, geotechnical and structural aspects [6]. One way to reduce the risk of an earthquake disaster is to plan, design and build earthquake-resistant buildings [7]. In other words, the community, including the contractors and the building designers, must be well educated and must have studied about earthquake resistant building technology through demonstrations, accompanied by direct training, as part of the socialization of the implementation of the new Indonesian building standards [8]. Although these building procedures were designed by applying the old Indonesian building standards [9], future training should include how to install a good and correct masonry wall in a reinforced concrete building, so that it can resist the huge ground movements due to an earthquake. Earthquakes that occur in a region are an event that has a return period. One method of hazard seismic calculation which is useful, in order to minimize the damage caused by an earthquake, is the Probabilistic Seismic Hazard Analysis (PSHA) method.

The PSHA method was first introduced by Cornell in 1968 [10] and it has continued to be popular as it is today. The advantages of the PSHA method include the possibility to take into account the influences of uncertain factors in the analysis, as well as the uncertainties of magnitude, location and the frequency of earthquake events. In the PSHA method, the uncertainty factors can be identified and estimated and then be led on to be further incorporated into a rational approach method, in order to obtain a more complete picture of the earthquake events. Another advantage of the PSHA method is that it is able to integrate hazards from a location against various earthquake sources [11, 21]. However, this method has several disadvantages, such as incomplete information about the dominant magnitude (*M*) and the dominant distance (*R*), whilst being unable to provide any ground motion for the earthquake analysis. The PSHA calculates the earthquake hazard based on a collection of results from all earthquakes and the ground motion events that may occur in the future. For that reason, the results of these seismic hazards, based on the PSHA, are required to undertake a deaggregation process, in order to obtain the magnitude and the distance that contribute to the earthquake hazard, by carrying out an SR Model software analysis.

The novelty of this current study was mainly focused on the history of time that is developed when based upon the history of the artificial time that matched to the location of the area under review. This is because each location has different soil layer characteristics. In the design of public buildings, the history of time is usually calculated from different locations, with buildings being designed or evaluated so that the results tend to be less accurate.

2. RESEARCH METHODS

The PSHA method that was used in this research was applied in order to determine a synthetic time history on the bedrock at the research location. Each location has a different time history, depending on the characteristics of the soil layers. The time history acceleration data on the bedrock was vertically propagated, so as to obtain the accelerated time history data at the surface ground level, which is directly affected by a condition of soil layers (N-SPT).

2.1 Research Instruments

This research was conducted by using various software that was aimed at facilitating the analyses processes. The list of software used in this study was as follows:

1. SR Model Software was developed by Makrup in 2009. This software was used to analyze the seismic hazards by using the PSHA method and it performed the deaggregation hazard analysis [12].
2. SeismoMatch Software was developed by Seismosoft. This software was used for scaling (matching) the spectrum responses and the time histories, so as to get a ground motion on the bedrock.
3. NERA Software (Nonlinear Earthquake Site Response Analysis) was developed by Bardet et al., in 2001. This software was used to analyze the wave propagation of the earthquake shear from the bedrock to the surface.
4. Microsoft Excel Software was used for the data analyses of the process results from the research area.

2.2 Identification of the Earthquake Source

The source of the earthquake hazards that were used in this study were taken from the sources of the earthquake faults and the subductions located in Java, South Sumatra and Sumba (NTT). The following map presented in Fig. 2 identifies the sources of the earthquakes showing the earthquake sources from the faults and the subductions. The reviewed faults and the subductions referring to Fig. 2 are depicted in Table 1.

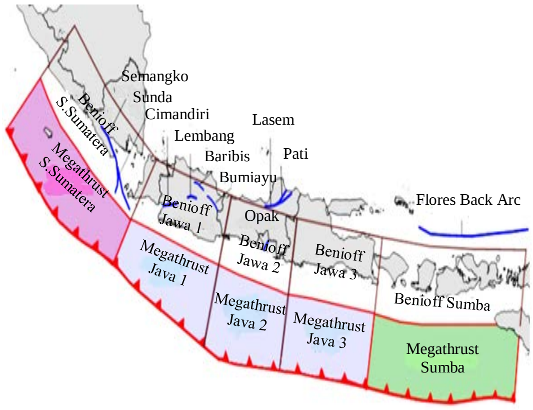

Fig. 2 Identification of the earthquake sources [13]

Table 1. Reviewed faults and subductions

No	Fault	Subduction
1	SC Sunda	South Sumatra Megatrust
2	Cimandiri	South Sumatra Benioff
3	Lembang	Java Megatrust 1
4	Baribis	Java Benioff 1
5	Bumiayu	Jawa Megatrust 2
6	Opak Fault	Jawa Benioff 2
7	Pati	Jawa Megatrust 3
8	Lasem	Jawa Benioff 3
9	Flores Back Arc	Nustra Megatrust
10	SC Sunda	Nustra Benioff

2.3 Earthquake Source Modeling

The use of an earthquake source modeling was based on a model of the three-dimensional earthquake source (3D source). The seismic earthquake zones were taken into account for 10 (ten) active faults and 10 (ten) subduction zones. The modeling in this study was adjusted to the specifications of the SR Model.

2.4 Determination of the Attenuation Functions

The attenuation equations described the earthquake wave propagations and the movement parameters of the soil in the forms of acceleration, velocity and the displacement from the location of the earthquake source, to the location under review. The expansion of the attenuation functions required much ground acceleration data, in order to obtain the new attenuation functions. This was because, in Indonesia, it does not have an attenuation function, so the determinations of the attenuation function referred to the equations of other countries' attenuation functions. The determinations of the attenuation functions were based on the similarities of the tectonic and the geological conditions in Indonesia.

2.5 Earthquake Hazard Analysis

A seismic hazard analysis was conducted by using the total probability theory as developed by McGuire in 1976 [14]. The analysis considered the effects of the geometry of the earthquake sources on a particular site, with a distance probability. It also predicted the probability of each source causing an earthquake at a certain magnitude, with a probability of the magnitude level, while considering the uncertainty of the magnitude parameters, the distance and the intensity is exceeded. The seismic hazard analysis was carried out by using SR Model software. The end result of the seismic hazard analysis was that the maximum unbounded earthquake acceleration for probability exceeded 2% in 50 years (2475 years re-quake period).

2.6 Hazard Deaggregation

A deaggregation hazard was aimed at analyzing the dominant magnitude (*M*) and the dominant distance (*R*) from the earthquake sources to the site under review. The dominant *M* and *R* values that were defined from the hazard deaggregation were very useful in determining the ground motion of acceleration of the usable soil at the building site. The sequential sources of the quake were assessed from the source of the subduction earthquakes.

2.7 Ground Motion

The dominant magnitude (*M*) and the dominant distance (*R*) values at the research location were essentially required to determine the ground motion design of the earthquakes, according to the research site. In Indonesia, the ground motion acceleration data is difficult to collect. Based upon the dominant magnitude and the dominant distance, the ground motions were established from the Peer Ground Motion Database website, followed by the processes of matching, when using the SeismoMatch software, in order to determine the synthetic ground motions on the bedrock.

2.8 Analysis of the Soil Dynamics Response

The analysis of the soil dynamics response in this research was vertically propagated to the surface by using the theory of single-dimensional wave propagation (1D). The analysis was conducted by inputting the synthetic ground motion data, then calculating the dynamic soil parameters, according to the log data of the reviewed location. The Borlog data that was used in this research was the result of the N-SPT at the location of the Alana Yogyakarta Hotel. The processes of wave propagation from the bedrock to the ground surface were analyzed by utilizing NERA software.

3. RESULTS AND DISCUSSION

3.1 Analysis of Time History on the Bedrock

3.1.1 Earthquake data collection and the earthquake magnitude uniformity

Information about earthquake events affecting Yogyakarta and its surrounding areas can be obtained by collecting earthquake catalogs from various sources, including both national and international institutions. In this study, the collected earthquake data consisted of various types of magnitude that had to be equated. Fig. 3 shows the distribution of the earthquake epicenters in the Yogyakarta Special Region and its surrounding areas from 1963-2018.

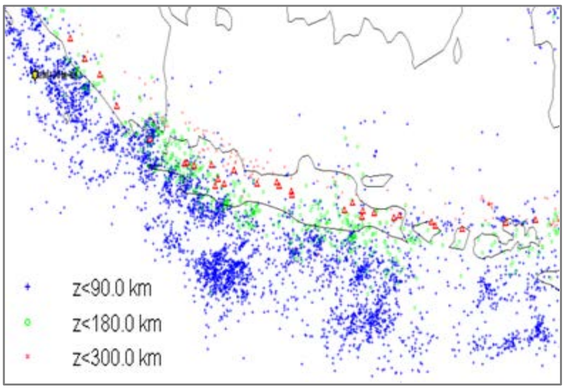

Fig. 3 Distribution of the earthquake epicenters in Yogyakarta and its surrounding areas from 1963-2018 (Modified from the ZMAP Program)

3.1.2 Separation of the main earthquake and the following earthquake

The data that was used for the hazard analysis was only for the main earthquakes (mainshock), so the separation processes between the main earthquake (mainshock) and the following earthquakes (the foreshock and the aftershock) were mandatory. The results of the declustering processes were included in the main earthquakes, or in the independent earthquakes (mainshock), with up to 696 events, as shown in Fig. 4.

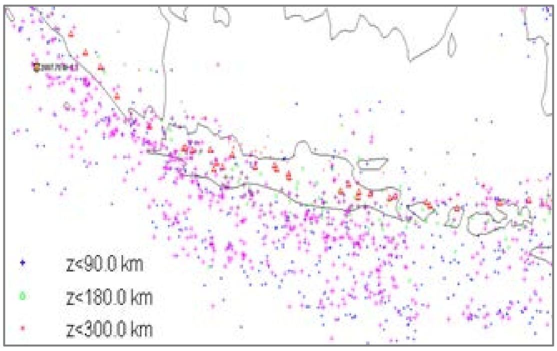

Fig. 4 Distribution of the main earthquakes in Yogyakarta and its surrounding areas from 1963-2018 (Modified from the ZMAP Program)

3.1.3 Identification and the modeling of the earthquake source

The method of earthquake source modeling was used to determine the hazard levels of earthquakes. An identification of the earthquake source was based on the geological, seismological and geophysical conditions. In this study, the earthquake sources were classified into subductions and fault zones, including the sources of Megathrust, the Benioff zone, and the Shallow crustal earthquakes.

The source of the subduction earthquakes model was based on the well-identified seismotonic data. The parameters of the subduction model included the depth of the subduction model (latitude and longitude coordinates), the slope of the subduction (dip) and the subduction area depth. The subduction zones included the movements of the Eurasian tectonic plates. The source of the subduction earthquakes consisted of a megathrust zone (interplate) located at a depth of less than 50 km and a zero zone (intraslab) at a depth of over 50 km. The sources of the Yogyakarta Special Region earthquakes were the active faults around Java.

The earthquake source modeling that was adopted in the earthquake hazard analysis of Java and its surroundings, with the sources of the subductions and the shallow crustal earthquakes when using a three-dimensional model (3D), was adjusted to the specifications of the SR Model software. In order to model the 3D earthquake sources, the subduction zones (dip) in Java and its surrounding areas were significantly needed. The general picture in the subduction zones was given from the tomography model, as well as from the cross-sections of the hypocenter distributions around the Java region. In this study, the overview of the subduction zones was based on five cross-sectional areas of the hypocenter distributions around the Java region (shown in Fig. 5). The megathrust zones were at a depth of approximately 50 km, while the Benioff zones were at depths of more than 50 km.

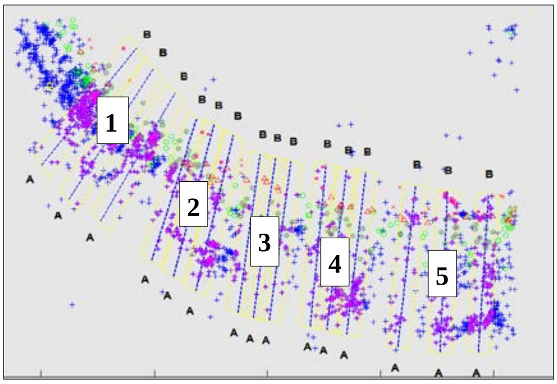

Fig. 5 Location of the cross pieces in order to provide an overview of the subduction angles at the subduction zones of Java and its surroundings

Table 2 shows the results of determining the angles of subduction in 5 areas in the Java subduction zones. Fig. 5 presents the details of the locations for the 5 cross pieces, in order to give an overview of the subduction angles at the subduction zones of Java and its surroundings. The supporting angles (dip) were accomplished from the average angles of the support of three cross sections in each area.

Table 2 The average angles of support

Area	The average angles of support	
	Megathrust	Benioff
1	8.333°	52.667°
2	7.000°	40.333°
3	13.667°	53.667°
4	14.667°	41.333°
5	8.667°	42.333°

3.1.4 Attenuation functions

Although many attenuation equations have currently been generated, Indonesia has not yet had sufficient ground motion data for the manufacture of attenuation functions. Therefore, the use of attenuation functions that were derived from other countries was unavoidable. The selections of the attenuation functions were based on similar geological and tectonic conditions of the region, from which the attenuation formulas were established. The attenuation functions were used to determine the acceleration peaks of the earthquakes, which decreased due to the influences of distance. These functions were used to connect the magnitude of the earthquakes and the distances to the locations of the epicenter, with the parameters of the ground movements (acceleration spectra) in the location under review.

In this study, the attenuation functions that were available in the SR Model software were utilized in analyzing the seismic hazards. The attenuation formulas were useful for each earthquake source model, as follows:

1. Attenuation functions for the shallow crustal quake source (fault or faults):
   a. Boor-Atkinson Attenuation Function (2006-NGA) [15],
   b. Sadigh Attachment Function (1997) [16],
   c. Chiou-Young Attenuation Function (2006-NGA) [17].
2. Attenuation functions for the subduction earthquake sources (Megathrust and Benioff):
   a. Youngs et al., (1997) [18],
   b. Atkinson Boore, (2003) [19].

3.1.5 Seismic hazard curve results of the PSHA

The seismic hazard curve was a relationship between the mean probability of it being exceeded annually (annual rate of exceedance) and the acceleration amplitude. The amount of acceleration is stated below in unit g (gravity). This curve used the logarithmic scale in depicting the seismic hazard that had occurred. In this study, there were several spectral periods on the seismic hazard curves. The seismic hazard curves are presented in Fig. 6.

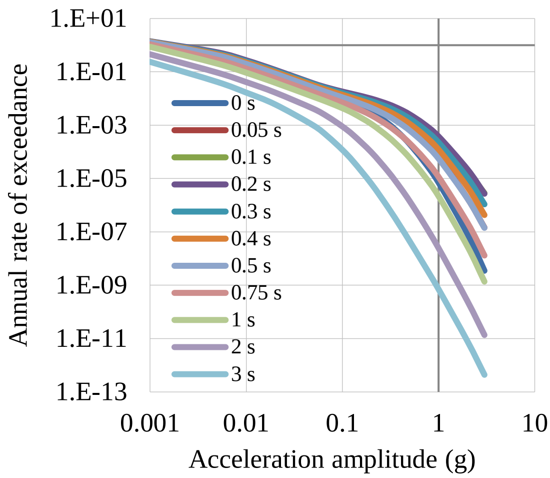

Fig. 6 Seismic hazard curves

3.1.6 Results of the Earthquake Hazard Analysis (PSHA)

The seismic hazard analysis was conducted in this study by using the PSHA and it continued with the SR Model software. It was limited to the probability of exceeding 2% within 50 years of the buildings' age, or in an equivalent to a 2475 years return period. The results of the seismic hazard analysis at the subductions and the shallow crustal earthquake sources, in the form of a uniform hazard response spectrum, are tabulated in Table 3. The values of the PGA on the bedrock at the research site with a 2% probability of being exceeded in 50 years was obtained at 0.4198 g. Fig. 7 shows a graph of the uniform hazard response spectrum in this study.

Table 3. Uniform hazard response spectrum

Period (s)	Spectral acceleration (g)
0	0.4198
0.05	0.6476
0.10	0.9294
0.20	0.9902
0.30	0.8951
0.40	0.7276
0.50	0.6117
0.75	0.4138
1.00	0.2949
2.00	0.1343

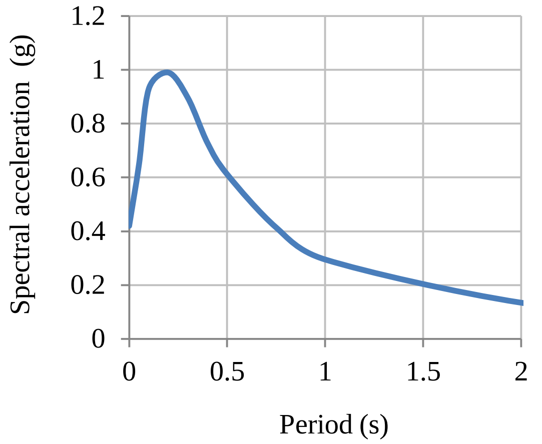

Fig. 7 Graph of the uniform hazard response spectrum

In 2017, the Ministry of Public Works issued an Earthquake Map of Indonesia [20]. On the map, there is an earthquake acceleration map on the bedrock with a 2% probability within 50 years. The map shows that in the Yogyakarta region, it had peak ground accelerations at the bedrock of between 0.40 - 0.50 *g*. This indicated that the resultant values of the PGA on the bedrock were in accordance with the expected Indonesia Earthquake Map Team of 2017.

3.1.7 Hazard deaggregation

A hazard deaggregation is a process of analysis of various sources of earthquake hazards that affect a location, by predicting the dominant magnitude and the dominant distance. Therefore, this process uses a probabilistic approach, which means taking into account all of the possibilities of each earthquake source, based on the parameters that it has. In this study, the resulting hazard deaggregation was calculated based on the source of the subduction earthquakes at the hotel building's location. The deaggregation processes were carried out by using SR Model software, with a probability of it being exceeded by 2% in 50 years. The results of the hazard deaggregation are depicted in Fig. 8.

Based on the results of the deaggregation process, it was found that the dominant distance (*R*) that could affect the research location was 226.0829 km, with a dominant magnitude (M_w) of 7,1597. The dominant sources of the earthquakes that affected the research location were originated from Java Megathrust 2, with a hazard contribution of 98.4464%.

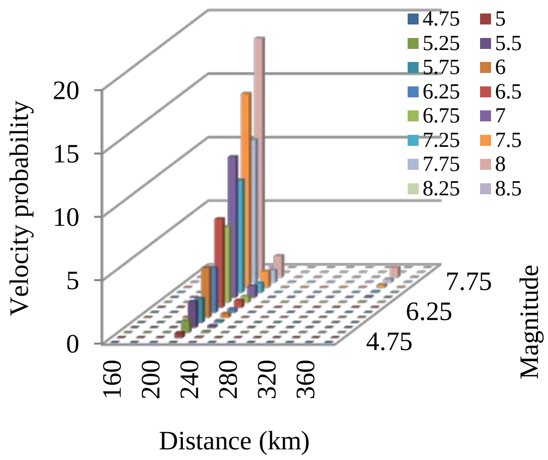

Fig. 8 Hazard deaggregation result

3.1.8 Ground motion data

After the deaggregation process, the dominant distance (*R*) and the dominant magnitude (M_w) parameters were deliberated as a reference in determining the ground motions, in accordance with the conditions of the research location. The ground motions were defined from the PEER Ground Motion Database website. By inputting the availability parameters, the appropriate ground motions were then generated. The ground motions were taken when they had proximities of magnitude (M_w) and distance (R) to the results of the deaggregation.

3.1.9 Spectral matching

After obtaining the time history data on the PEER Ground Motion Database website that matched the characteristics and the sources of the earthquakes in the reviewed location, this time history was used in the spectral matching process. The data from the time history that was obtained was a Hector Mine earthquake in 1999 recorded by the LA - Griffith Park Observatory earthquake recording station. This earthquake had a magnitude of 7.13, with a distance of 185.92 km. Fig. 9 shows the earthquake time history record data and Fig. 10 presents the artificial time history as was resulted in this study.

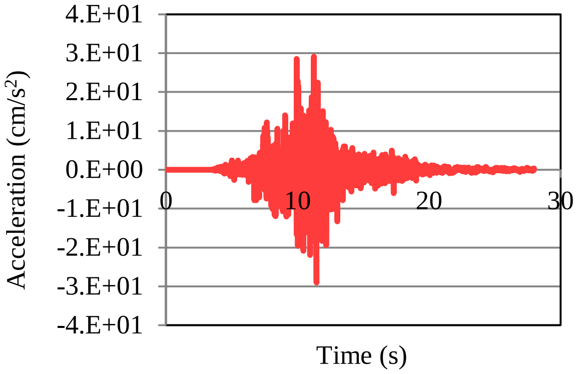

Fig. 9 Time history Hector Mine 1999

The time history data in Fig. 9 was adopted based on the earthquake recordings from other regions, so it was essentially being undertaken to match the conditions of the research location. The time history was scaled to the response spectral target in the location reviewed. In this study, the target spectral was the spectral response on the bedrock, as presented in Fig. 7. The target response spectral was referred to in the spectral matching analysis for the time history.

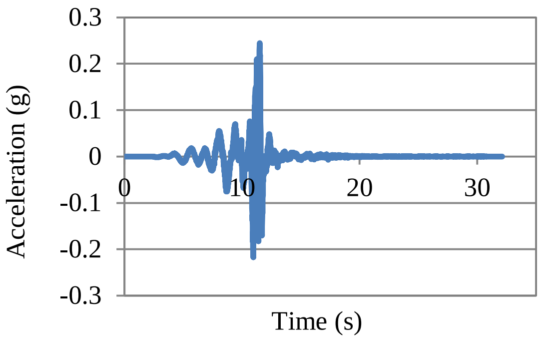

Fig. 10 Time history matching

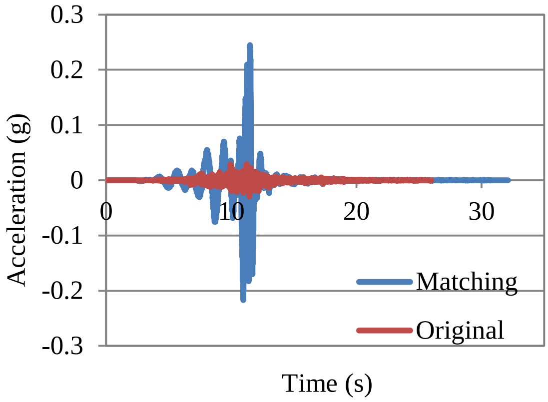

Fig. 11 Comparison of the time history

A comparison of the time history before and after the matching processes is shown in Fig. 11, showing that the peak acceleration increased from the previous of 0.0296 g to the recent of 0.2447 g. This result was influenced by the adjusted spectral response based on its value. This process was depicted in the matching results of the spectral response of the initial conditions to the target. The results are presented in Fig. 12.

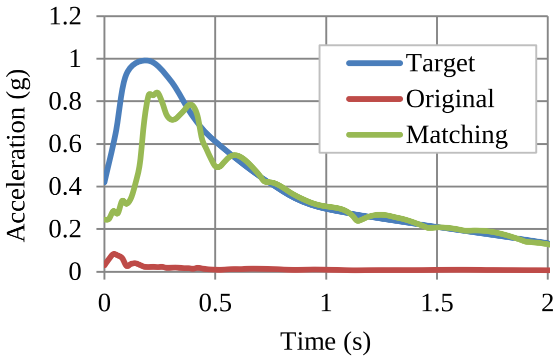

Fig. 12. Response spectrum acceleration

The original spectral response was the novel response spectrum acceleration of the Hector Mine earthquake. The response spectrum target was the response spectrum acceleration obtained from the seismic hazard analysis processes at the research location. From the Hector Mine response spectrum data and from the response spectrum acceleration target, the Seismosoft software performed the matching processes, in order to obtain a scalable response spectrum that could be used in the analyses processes. This response spectrum was the response spectrum of artificial time.

3.2 Analysis of Time History on the Surface

3.2.1 Analysis of the soil dynamic response

An analysis of the soil dynamic response was conducted in order to determine the values of the earthquake accelerations that occurred on the surface. The analysis included determining the dynamic parameters of the soils and the propagation of the waves from the bedrock to the soil's surface. The soil parameters used were obtained from the soil test results in the form of Borlog data at the research location. The location of this research is on the coordinates of longitude - 7.739329° LS and latitude 110.377262° East.

3.2.2 Soil dynamic parameter

The soils had a layered texture. Each layer had different properties that had different patterns and behavior in the wave propagation processes. Therefore, the soil dynamic parameters needed to be analyzed. The soil dynamic parameters were required for the analysis of the soil dynamic response. These parameters were obtained based on a ground investigation at the location under review. The required dynamic soil parameters were the maximum shear modulus (G_{max}) and the shear wave velocity (V_s).

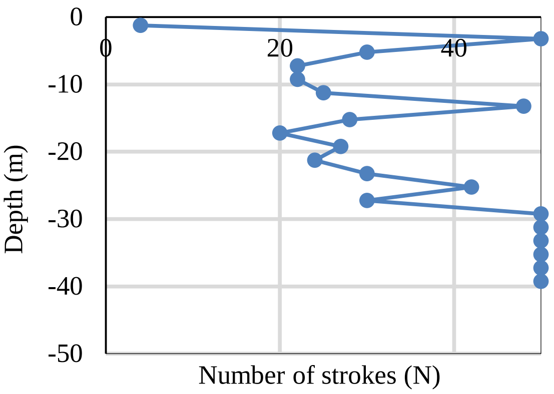

Fig. 13 Borlog data

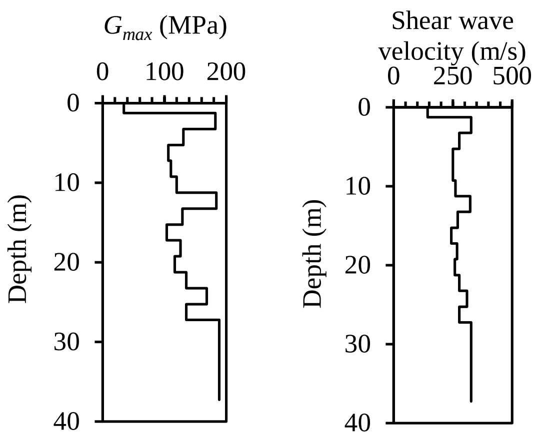

Fig. 14 Correlation of G_{max} and V_s to a depth at the research location

In this study, the analysis of the soil parameters was taken by inserting the dynamic parameters of the soils on each layer. This analysis process was conducted by using NERA. The soil dynamic parameters were obtained from the correlation of the Borlog data in the form of N-SPT, by using equations that have been researched by geologists. The N-SPT data in the area of review is presented in Fig. 13. From the Borlog data, the shear wave velocity wear (V_s disposable) was used for the analysis by using NERA. The resulting graph of the producing propagation of G_{max} and V_s to depth is presented in Fig. 14.

3.2.3 Time history acceleration on the surface

The analysis of earthquake wave propagation from the bedrock to the surface was carried out by using NERA. The process of NERA has the stages of scaling and filtering of the input data of the artificial time history located on the bedrock. Fig. 15 to Fig. 17 present the results of the time history input, the scaled acceleration and the filtered acceleration.

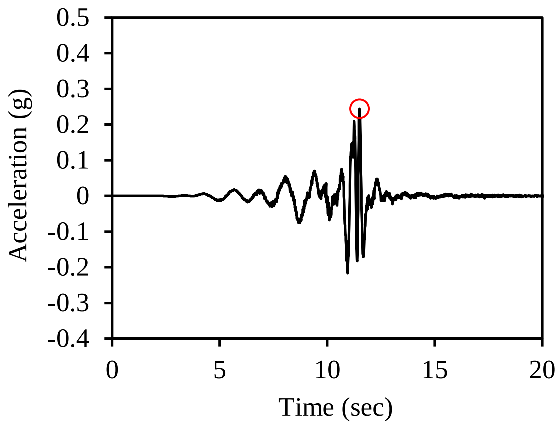

Fig. 15 Time history acceleration on the bedrock

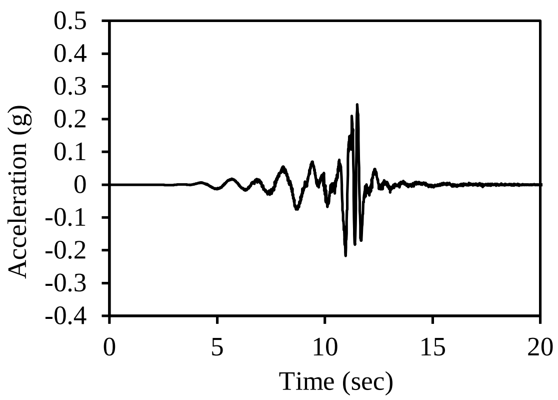

Fig. 16 Scaled acceleration with NERA

The earthquake wave propagation from the bedrock to the surface was compiled after the analysis process of the time history on the bedrock. In this process, the dynamic ground parameters in each layer were inserted into NERA. The dynamic soil parameters included the maximum shear modulus value (G_{max}) and the shear wave velocity (V_s). The results of the surface acceleration time after being moored from the bedrock are shown in Fig. 18.

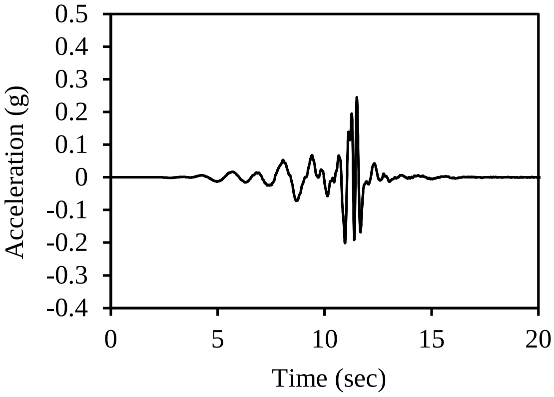

Fig. 17 Filtered acceleration with NERA

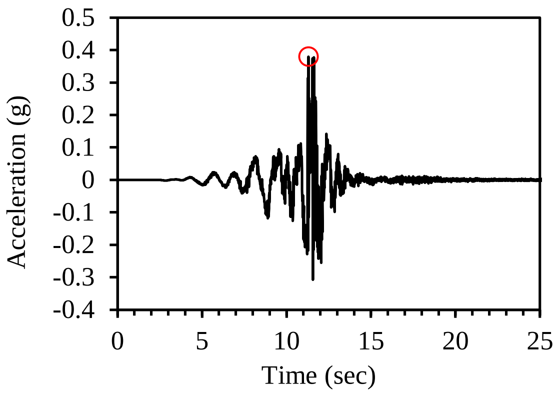

Fig. 18 Time history acceleration on the surface

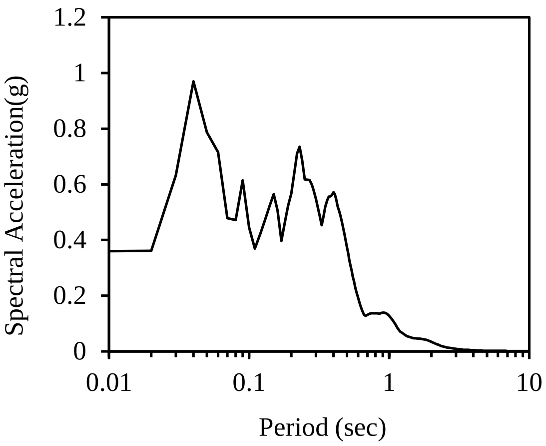

Fig. 19 Response spectral acceleration on the surface

Based on the wave propagation results, the peak acceleration values increased on the surface after being propagated from the bedrock. These increases are called the amplification factor. This factor may change according to the local soil conditions. In this study, the acceleration of the peak time acceleration time on the bedrock was 0.2447 g, while the peak acceleration at the acceleration time on the surface increased to 0.379 g. From the NERA output results, the response of the spectral acceleration, the spectral velocity, and the spectral displacement at the surface was also obtained, as depicted in Fig. 19 to Fig. 21.

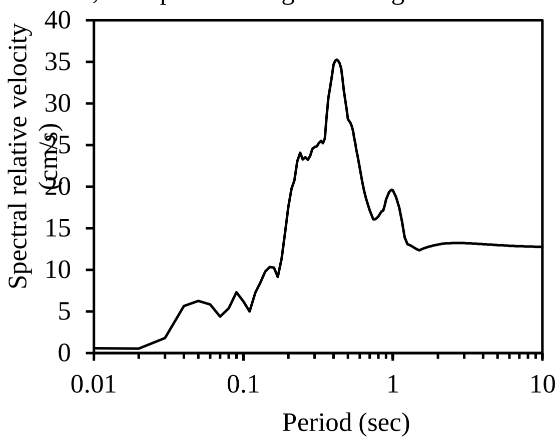

Fig. 20 Response spectral velocity on the surface

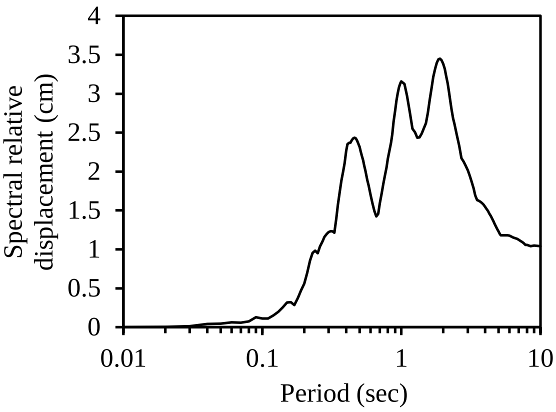

Fig. 21 Response spectral displacement on the surface

4. CONCLUSION

From a summary of the seismic hazard analysis, some conclusions can be drawn. The results of the hazard deaggregation analysis that was conducted at the Alana Hotel Yogyakarta location for probabilities exceeding 2% in 50 years produced a dominant magnitude (M_w) of 7.1597, with a dominant distance (R) of 226.0829 km. The peak ground acceleration value in the bedrock in the form of the historical acceleration time after performing the spectral matching analysis process at the site was 0.2447 g. The acceleration of the soil peaks on the surface in the form of the historical acceleration time that spread from the bedrock to the ground level at the study site was 0.379 g, resulting in amplification factors in the earthquake wave propagation of 1.55. The difference in the time historical acceleration between the bedrock and the ground level requires a further review of the building evaluations.

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6. REFERENCES

[1] Aldiamar F., Earthquake Risk Analysis and Making Design Response Spectrum for Suramadu Bridge with 3D Earthquake Source Modeling, 2007.

[2] Sulistyanto I.G., Geography 1: for High School / Madrasah Aliyah Class X, 2009.

[3] Widodo P., Seismology Engineering & Seismic Engineering, 2012.

[4] BMKG, Indonesia is prone to earthquakes & tsunamis, 2010.

[5] USGS, USGS Earthquake Preliminary Report, 2006.

[6] Mahesworo R.P., Proposed Ground Motion for Four Large Cities in Sumatra Region Based on Seismic Hazard Analysis Using a 3-Dimensional Earthquake Source Model, 2008.

[7] Irsyam M., Sengara I.W., Adiamar F., Widiyantoro S., Triyoso W., Natawidjaja D.H., Kertapati E., Meilano I., Suhardjono, Asrurifak M., and Ridwan M., Summary of Study Results Indonesian Earthquake Map Revision Team, 2010.

[8] Teguh M., Experimental Evaluation of masonry infill walls of RC frame building subjected to cyclic loads, Procedia Engineering, Vol 171, 2017, pp 191-200.

[9] Tanjung J., Maidiawati and Alfajri A., Effect of Brick Masonry Infills to Seismic Capacity of Indonesia Multi-Story RC Building, International Journal of GEOMATE, Vol 16, Issue 57, 2019, pp 42-48.

[10] Cornell C.A., Engineering Seismic Risk Analysis, Bulletin of the Seismological Society of America, 58, 1968, pp. 1583-1606.

[11] Fauzi U.J., Indonesian Deaggregation Map Based on Probability Analysis with Three-Dimensional Earthquake Source, 2011.

[12] Lalu M., Development of Hazard Deaggregation Map for Indonesia Through Making Software with Three-Dimensional Earthquake Modeling, 2009.

[13] Bambang S., Java Region Earthquake Hazard Deaggregation Map and Ground Motion Recommendations in the Four Regions, 2013.

[14] McGuire R.K., FORTRAN Computer Program for Seismic Risk Analysis, U.S. Geol. Surv., Open-File Rept. 76-67, 1976.

[15] Boore D.M., and Atkinson G.M., Ground Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5% Damped PSA at Spectral Periods between 0.01 s and 10.0 s: Earthquake Spectra, Vol.24, No.1, 2006.

[16] Sadigh K., Chang C.Y., Egan J.A., Maksidi F., and Young R.R., Attenuation Relationship for shallow Crustal Earthquake Based on California Strong Motion Data, Seismological Research Letters, Seismological Society of America, Volume 68, 1997.

[17] Chiou B. S.-J., and Youngs R.R., Chiou and Youngs PEER-NGA Empirical Ground Motion Model for the Average Horizontal Component of Peak Acceleration, Peak Velocity, and Pseudo-Spectral Acceleration for Spectral Periods of 0.01–10 sec, Interim Report Submitted to PEER, 2006.

[18] Youngs R.R., Chiou, S.-J., Silva W.J., and Humphrey J.R, Strong Ground Motion Attenuation Relationships for Subduction Zone Earthquakes, Seismological Research Letters, Vol. 68, No. 1, 1997, pp 58-73..

[19] Atkinson G.M. and Boore D.M., Empirical Ground Motion Relations for Subduction-Zone Earthquakes and Their Application to Cascadia and Other Region, Bulletin of the Seismological Society of America, Vol. 93, No. 4, 2003, pp. 1703-1729.

[20] Indonesia Earthquake Source and Hazard Map for 2017, Housing and Settlement Research and Development Centers, Research and Development Agency, Minister For Public Works and Human Settlements, Bandung, 2017.

[21] Erlangga W., Response Evaluation of Multi-story Building Structures Using FEMA 310 and ATC-40 Based on the Time History of Seismic Hazard Analysis, MS Thesis, Department of Civil Engineering, Islamic University of Indonesia, Yogyakarta, 2018.