Liquefaction potential study under Ijo Balit weir in East Lombok Indonesia

Lalu Ibrohim Burhan[1], Hanindya Kusuma Artati[2,*], Lalu Makrup[2], Elvis Saputra[2]

[1]Faculty of Civil Engineering, Universitas Gunung Rinjani, Lombok, NTB
[2]Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia

Article Info
***Article history*:**
Received:
November 22, 2025
Revised:
June 11, 2025
Accepted:
June 11, 2025
Available online:
June 23, 2025

***Keywords*:**
earthquake wave
acceleration
liquefaction

Abstract
Liquefaction phenomenon can be occurred in the sandy soil. Caused by an earthquake shaking on the sandy soil so the shear stress of the soil will be lost and the soil seem like liquid. Liquefaction in a site can cause the building on soil surface in the site can be crack or collapse. Therefore, it is need to study to review the liquefaction potential that will be occurred under Ijo Balit weir East Lombok. In general, the liquefaction, trigger by the earthquake shaking. Based on this condition so can be developed the earthquake shaking in form of the earthquake acceleration for time history. The time history of the earthquake wave can be developed in ground surface based on the spectral-matching-procedure with the target spectrum is design spectrum. Based on ground surface time history then can be calculated liquefaction potential on the soil layer under the Ijo Balit weir East Lombok. The study result can be mention that the soil layer in the site is not experience liquefaction.

Corresponding Author:
Hanindya Kusuma Artati
hanindya.artati@gmail.com

Introduction

Liquefaction is a nature disaster from earthquake that reduce the strength and stiffness of the soil layers. This condition causes the soil layers seem as liquid. Liquefaction on soil surface layer or under soil surface layer can cause the building in the ground surface to be damaged and collapse. Therefore, it is required to do the liquefaction study for the location where the building be built. Liquefaction can be triggered by a earthquake event. The earthquake wave can disturb the soil around the building. If the building location is in a saturated sandy soil layer and in the place the earthquake is happened, so the liquefaction can be occurred in around of the building. Because the liquefaction is triggered by the ground vibration caused by earthquake, is needed to developed earthquake ground motion each layers so that the liquefaction potency can be calculated. The earthquake ground motion can be determined by deterministic, probabilistic or code method. According to develop the earthquake ground motion, some experts had made the work to develop the earthquake ground motion, deterministically, probabilistically, and develop the ground motion by the code (SNI 2019). Petersen, et al (2004), had research result the PSHA at Sumatra Indonesian and south Malaysian Peninsula areas. Petersen, et al (2008), have presented the seismic hazard map for South East used PSHA. Irsyam, et al (2008), used PSHA to produce the earthquake acceleration map for Sumatra and Java and conduct the microzonation study for Jakarta. Irsyam, et al.(2010), revision of the national code of the earthquake resistant building. Sengara et al.

(2015), developed the seismic hazard map for Sumatra use PSHA.

The earthquake acceleration time history to the civil engineering purpose, many experts have done the thing. Wood and Hutchinson (2012), a probabilistic seismic hazard analysis was used to choose the ground motion, and additionally, a new time history was generated to match a specific target response spectrum. Carlson et al. (2014), the liquefaction potential at a site can be assessed by investigating the amplification characteristics of seismic shear wave velocity in the vicinity of the ground surface. Bayati and Soltani. (2016), a seismic acceleration time history was selected based on estimation results, and from this, an artificial time history was deterministically generated for seismic design of reinforced concrete (RC) structures to assess collapse prevention. Pavel and Vacareanu (2016), actual acceleration time histories were selected that design ground motion was derived using probabilistic seismic hazard analysis in conjunction with seismic code provisions, and a new time history was subsequently generated to match a specific target spectrum. Makrup and Jamal (2016), the artificial time history was developed an artificial time history was generated through probabilistic seismic hazard analysis and subsequently calibrated via spectral matching. Makrup and Muntafi (2016), artificial ground motions for Semarang and Solo, Indonesia, were generated used probabilistic seismic hazard analysis. Makrup (2017), ground motion was derived using probabilistic seismic hazard analysis in conjunction with seismic code provisions. The earthquake can trigger the liquefaction phenom in a site, many experts have given the papers about that. SNI 1726 (2019), earthquake Resistance Planning Procedures for Building and Non-Building Structures, National Standardization Agency, Jakarta. Artati et. Al (2023), determine the liquefaction potential used deterministic seismic hazard analysis method. Tanjung, M.I. (2017), Screening Analysis of Slope Stability of Earthquake-Resistant Embankment Dams in Indonesia. Nicolaou (1998), get the earthquake acceleration for a particular site. Depiction of the strategy based on the fundamental thought is that an genuine movement can be sifted in recurrence space by its unearthly proportion with the target range. The Fourier stages (nonexistent portion) of the motions stay unaltered amid the complete method. Spectral matching method is complicated enough if it is calculated with manual manner, so it is needed computer program to make calculation. In the study was used SPECMATCH software developed by Makrup (2016) to determine the time history design on study site. Seed, H. B. and Idriss, I. M. (1982), develop involve between ground motions and soil liquefaction during earth-quakes.

In this study will be determine the liquefaction in each layer based on earthquake time history developed by SNI 2019 code. Site of the study is Ijo Balit weir in East Lombok Indonesia Figure 1.

Figure 1. Drill log Ijo Balit Weir (BH_1 and BH_2)

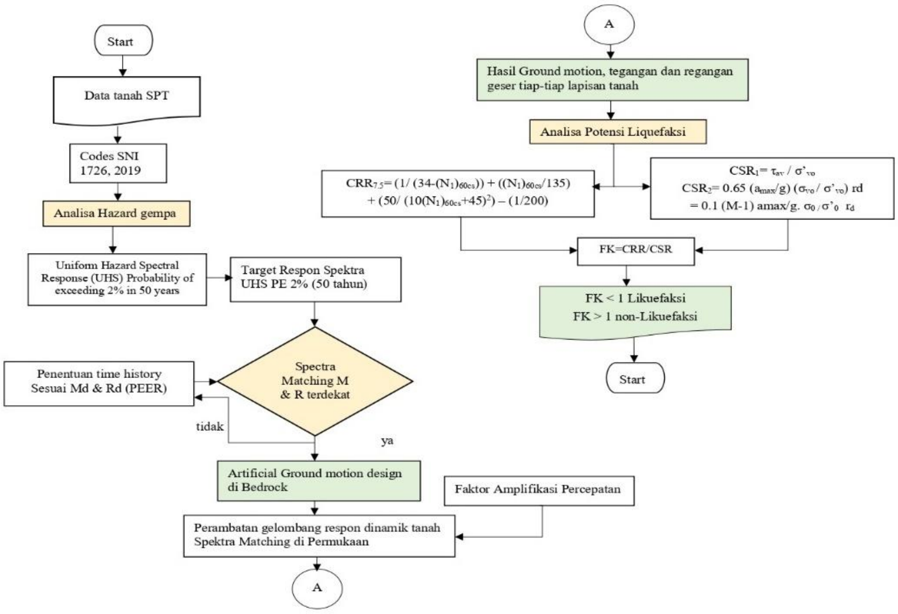

Figure 2. Flowchart research methodology

Metodology

The study was conducted based on Bore Hole 1 and BH 2 data at the Ijo Balit Lombok dam. The target spectrum response was obtained from based on the Indonesian seismic hazard map (SNI 2019), which was then spectral matching was carried out against the actual time history can be taken from the time history catalogue of the California University of Berkley USA. Spectra matching is carried out with the help of SPECMATCH software with the following procedure. The procedure is rehashed iteratively until the required coordinating is accomplished for a certain extend of periods. The first step is select the target spectrum, SAtarget(T), and Time History (TH), THactual(t). The response spectrum of THactual(t) is calculated using the same damping ratio as that of the target spectrum. Subsequently, the spectral ratio, SPR(T), is obtained by dividing the response spectrum of THactual(t) by the target spectrum, where T represents the spectral period

$$SPR(T) = \frac{SA_{target}(T)}{SA_{actual}(T)} \tag{1}$$

The frequency domain SPR(ω)

$$FILT(\omega) = \begin{cases} 1, & \omega < \omega_{\min} \\ SPR(\omega), & \omega_{\min} \le \omega \le \omega_{\max} \\ 1, & \omega > \omega_{\max} \end{cases} \tag{2}$$

where ω is the cyclic frequency, and ω_{min}; ω_{max} are minimum and maximum frequency for matching.

The Fourier spectrum, $f_{actual}(\omega)$ of $TH_{actual}(t)$ is obtained using the Discrete Fourier Transform (DFT) algorithm.

$$f_{filtered}(\omega) = FILT(\omega) \times f_{actual}(\omega) \tag{3}$$

The time history with the desired frequency characteristics is obtained by applying an inverse Fourier transform to derive TH(t), TH(t) is calculated. An estimator for this error is given by:

$$|Error|_N \% = 100 \frac{\sqrt{\int_{T_A}^{T_B} (S_a^{scaled} - S_a^{target})^2 dT}}{\int_{T_A}^{T_B} S_a^{target} dT} \quad (4)$$

where $S_a^{matching}(T)$ is a reaction range time history.

The spectral matching results will show the target time history which is the maximum earthquake acceleration in bedrock. Time history on bedrock will be propagated to the surface using non-linear one-dimensional which will obtain maximum acceleration on the surface. The results of the maximum surface acceleration will be used to analyze the potential for liquefaction in the Ijo Balit Lombok dam area.

Analysis and Discussion

The stages of analysis carried out in this research will be explained as follows.

(1) Soil site class determination

Before the computation to determine the target spectrum based on SNI 2019 code, so it has to be known the soil site class of the location for study. Soil site class is determined based on the mean N-SPT value of a drill log in Ijo Balit weir location, Figure 1. The equation that can be use is:

$$\bar{N} = \frac{\sum_1^m d_i}{\sum_1^m d_i/N_i} \quad (5)$$

where:
$\bar{N}$ = mean N-SPT
d_i = thick of the ith layer
N_i = value of N-SPT of ith layer.

N-SPT data of the drill log in Figure 3. From the N-SPT data Figure 3 can be computed mean N-SPT value by Equation 5. Mean N-SPT of the calculation result ($\bar{N}$) = 38.102.

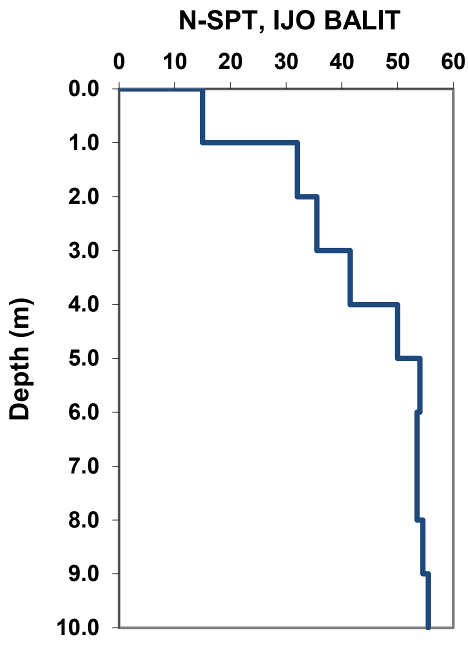

Figure 3. Drill log result under Ijo Balit weir in N-SPT value

Based on mean N-SPT 38.102 and soil site classification of the ASCE on Table Soil Site Classification on ASCE Code can be found that in the Ijo Balit weir location has the soil classification is D which arrange Vs 66 to 1200 ft/s and 370 to 760 fts, N value between 15 to 50 and Su at 1000 to 2000 psf or 50 to 100 kPa.

(2) Spectral matching

To find the design acceleration time history on the surface is called design time history on the surface and in the base rock, can be applied spectral matching method. Spectral matching will be analyzed in time domain or frequency domain. This study aims to develop a design time history. The spectral matching technique in frequency domain condition has previously been utilized. The earthquake acceleration time history, referred to as the actual time history, can be obtained from earthquake data catalogues provided by official seismic recording institutions. The actual time history can be taken from time history catalogue of the California University of Berkley USA in website name is NGAWET and NGAEAST. In this study, the time history of the 1976

Friuli, Italy earthquake, Figure 4, was used as the basis for generating a resulting time history, referred to as the design time history.

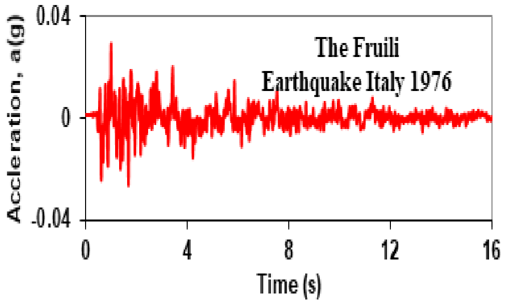

Figure 4. Time history of Fruili earthquake Italy 1976

(3) Actual time history

This actual time history serves as the base for developing a modified or synthesized time history. The response spectrum corresponding to this time history is presented Figure 5.

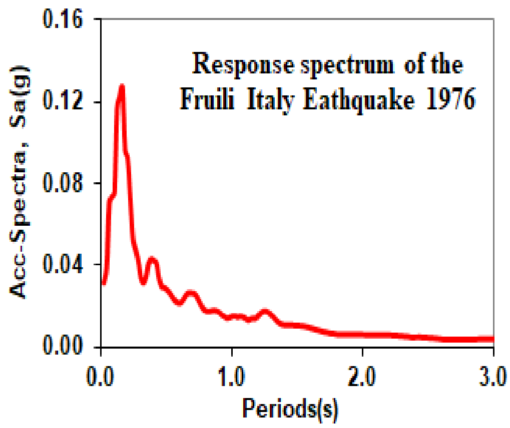

Figure 5. Response spectra

(4) Target spectrum

The target response spectrum serves as the primary input for the spectral matching method. Based on Indonesian seismic hazard map (SNI 2019), Lombok islands, in general pound acceleration for 0.2 second period in range 1.0g – 1.2g. For this 0.2 second it is taken acceleration (Ss) = 1.1g and for 1.0 second period is pound acceleration 0.4g-0.5g. Therefore for 1.0s period is taken acceleration (S_1) = 0.45g. Based on Ss = 1.1g and S_1 = 0.45g can be computed the parameter to determine design spectrum for Ijo Balit weir.

From Table Code Amplification factor FA for Ss = 1.1g is pound the amplification factor (Fa) = 1.06

From Table Amplification factor Fv, for S_1 = 0.45g is pound the amplification factor (Fv) = 1.85

From the value of Fa and Fv above can be calculated the other parameter value of design response spectra as follow, Figure 6.

S_{MS} = Fa Ss = 1.06 (1.1) = 0.901g

S_{DS} = 2/3 S_{MS} = 0.6007g

S_{M1} = Fv S_1 = 1.85 (0.45) = 0.592g

S_{MS} = 2/3 S_{M1} = 0.3947g

Ts = S_{MS}/S_{DS} = 0.3947/0.6007 = 0.657 s

T_0 = 0.2 Ts = 0.131 s

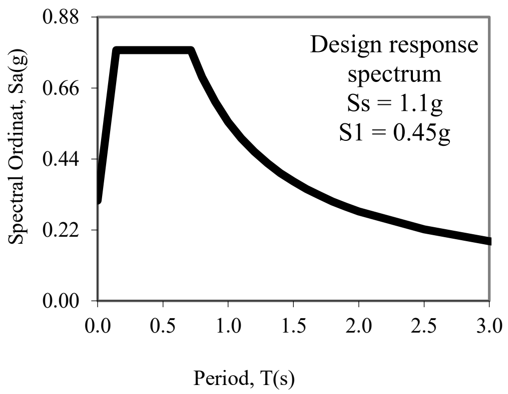

Figure 6. Design spectrum for Ijo Balit weir location

The design spectrum collected from target spectrum to process the spectral matching procedure to determine acceleration time history on the ground surface for Ijo Balit weir location.

(5) Spectral matching result

Spectral matching is performed from actual response spectrum and target spectrum, where shown in Figure 5 is adjusted to match the characteristics of the target spectrum in Figure 7.

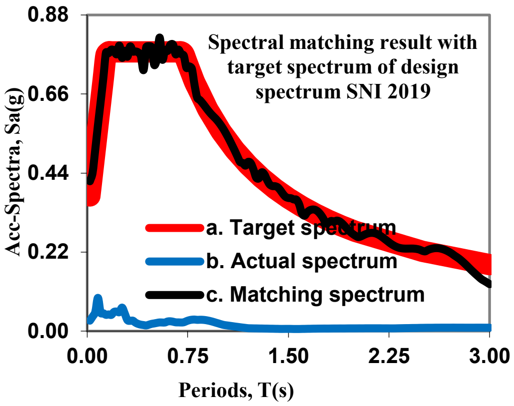

Figure 7. Spectral matching result based on Fruili Italy earthquake 1976

Result of the response spectra is showed in Figure 7.

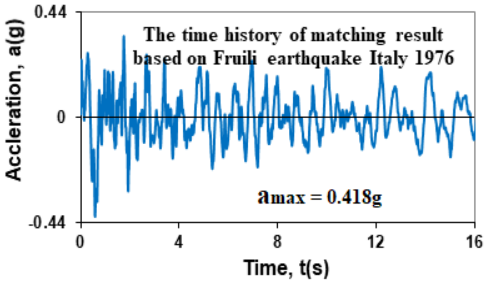

Figure 8. Design time history of the Ijo Balit weir East Lombok, Indonesia

The time history Figure 8 is a design time history in the ground surface that be utilized to conduc the liquefaction potential for Ijo Balit weir East Lombok. From time history Figure 8 the maximum acceleration (a_{max}) is = 0.418g.

(6) Determine the potential liquefaction

The earthquake shaking cause liquefaction which the phenomenon was reduced the strength and stiffness of the soil layer seem as liquid. Analysis of liquefaction potential is done on Ijo Balit weir East Lombok with the number of layers is 10. Graph in Figure 8 is showed the maximum acceleration in the soil surface is (a_{max}) = 0.418g.

In Lombok 2022 the earthquake has been occurred with magnitude M = 4.2 and M = 7.1 in 2023. In the following, with acceleration = 0.0.418g and Lombok earthquake 2023 magnitude M = 7.1, liquefaction potential for Ijo Balit weir calculated based on simplified method of Seed. Some parameter that are needed to determine for the liquefaction analysis is in the following.

Gs (specific gravity). For Ijo Balit weir, value of Gs = 2.58 and void number (e) = 0.829. Based on Gs and e, so the following soil parameter value can be computed.

γ_d (dry volume weight)

$$\gamma_d = \frac{G_s \gamma_w}{1+e} = 1.411 \text{ ton/m}^3 \quad (6)$$

γ_{sat} (saturated volume weight)

$$\gamma_{sat} = \frac{(G_s+e)\gamma_w}{1+e} = 1.8639 \text{ ton/m}^3 \quad (7)$$

γ' (un-saturated volume weight)

$$\gamma' = \gamma_{sat} - 1 = 0.8639 \text{ ton/m}^3 \quad (8)$$

Based on γ_{sat} and = γ' can be calculated vertical soil stress (σ_v) and ($\sigma_{v'}$). Computation for σ_v and $\sigma_{v'}$ is done in Table 1.

σ_v (vertical stress of un-disturb soil)

$$\sigma_v = \gamma \text{ h} \quad (9)$$

$\sigma_{v'}$ (vertical stress of dry soil)

$$\sigma_v' = \gamma' \text{ h} \quad (10)$$

Table 1. Computation of vertical stress of soil (σv and σv ′)

Depth (m)	γ_{sat} (ton/m³)	γ' (ton/m³)	σ_v' (ton/m²)	σ_v (ton/m²)	σ_v/σ_v'
0	0	0	0	0	0
1	1.8639	0.8639	0.8639	1.8639	2.1575
2	1.8639	0.8639	1.7278	3.7278	2.1575
3	1.8639	0.8639	2.5917	5.5917	2.1575
4	1.8639	0.8639	3.4556	7.4556	2.1575
5	1.8639	0.8639	4.3195	9.3195	2.1575
6	1.8639	0.8639	5.1834	11.1834	2.1575
7	1.8639	0.8639	6.0473	13.0473	2.1575
8	1.8639	0.8639	6.9112	14.9112	2.1575
9	1.8639	0.8639	7.7751	16.7751	2.1575
10	1.8639	0.8639	8.6390	18.6390	2.1575

Functions and curves to determine the liquefaction potential with simplified Seed methods used Stress reduction factor (r_d):

$$r_d = \frac{1-0.4113z^{0.5}+0.04052z+0.001753z^{1.5}}{1-0.4177z^{0.5}+0.05729z-0.006205z^{1.5}+0.00121z^{2}} \quad (11)$$

The alternatively r_d-value determined from the curve presented in Figure 9.

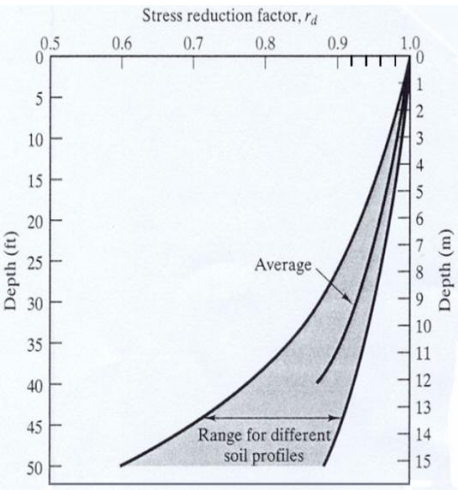

Figure 9. Stress reduction factor r_d

Cyclic stress ratio

$$CSR = \frac{\tau_{av}}{\sigma'_v} = 0.65\,\frac{a_{max}}{g}\frac{\sigma_v}{\sigma'_v}r_d \quad (12)$$

Correction factor of N-SPT

$$C_N = 1 - 1.25\,log\,\frac{\sigma'_v}{10.76391} \quad (13)$$

N’ (Corrected N-SPT)

$$N' = C_N \text{ N-SPT} \quad (14)$$

Relative density

$$D_r = \sqrt{\frac{N}{2.417965\sigma_v+17}} \quad (15)$$

f. The vertical shear strain ratio and vertical stress for dry soil, are derived from the work of Seed and Idriss and are represented within the framework of Equation (16).

$$\frac{\tau_{av}}{\sigma'_v} = 0.65\,\frac{a_{max}}{g}\frac{\sigma_v}{\sigma'_v}r_d \quad (16)$$

In the next step, the liquefaction potential can decided utilize the bend in Figure 10 The bend is created by Seed and Idriss base on the cyclic push proportion and N'.

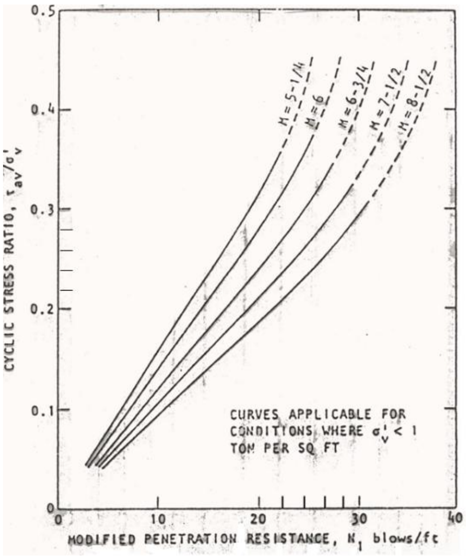

Figure 10. The curve to determine liquefaction potential

The letter L on the Table 2 gives indication that the soil layer liquefaction occurred, and letter N gives indication that the liquefaction is not occurred.

From Table 2 can be called that if the earthquake is occurred with magnitude 7.1 that produced acceleration 0.418g every soil layer on the drill result under Ijo Balit weir, the liquefaction is not occurred.

7. Conclusion

The research has produced the earthquake acceleration wave in the ground surface that is caused by an earthquake in form the acceleration time history. The maximum ground acceleration value from that time history with N-SPT data of the drill result is determine the liquefaction potential in Ijo Balit weir site.

From the calculation result is found that liquefaction is not occurred in every soil layer under Ijo Balit weir caused by the earthquake.

Table 2. Calculation of liquefaction potential

Soil layer	**Depth (m)**	**σ_v/σ_v'**	**N-SPT value**	**Dr**	**CN**	**N′**	**R_d**	**τ_{av}/σ_v'**	**L/N**
1	**1**	0	30	1.3949	1.3949	71.0815	0.9943	0.5829	**N**
2	**1**	2.1575	34	1.3070	1.3070	67.7653	0.9867	0.5784	**N**
3	**1**	2.1575	37	1.2123	1.2123	65.6003	0.9795	0.5742	**N**
4	**1**	2.1575	46	1.3133	1.3133	74.3732	0.9726	0.5701	**N**
5	**1**	2.1575	54	1.3659	1.3659	80.7662	0.9655	0.5660	**N**
6	**1**	2.1575	54	1.2261	1.2261	75.4215	0.9577	0.5614	**N**
7	**1**	2.1575	53	1.0917	1.0917	69.5896	0.9485	0.5560	**N**
8	**1**	2.1575	54	1.0178	1.0178	66.9881	0.9372	0.5494	**N**
9	**1**	2.1575	55	0.9555	0.9555	64.7119	0.9229	0.5410	**N**
10	**1**	2.1575	56	0.9022	0.9022	62.6855	0.9049	0.5305	**N**

8. Recommendation

The assessment of liquefaction potential can be conducted at each site based on the amplification of seismic shear wave velocity near the ground surface. Subsequently, for the other research can be worn out the other put.

References

Petersen M.D., Dewey J., Hartzell S., Mueller C., Harmsen S., Frankel A. D., and Rukstales K., (2004), Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula. Elsevier.

Petersen M.D., Harmsen S., Mueller C., Haller K., Dewey J., Luco N., Crone A., Rukstales K., and Lidke D., (2008), Probabilistic seismic hazard for Sooutheast Assia. International Conference of Earthquake Engineering and Disaster Mitigation, Jakarta, April 14, 15, 2008.

Irsyam M., Dangkua D.T., Hendriyawan, Hoedajanto D., Hutapea B. M., Kertapati E.K., Boen T., and Petersen M. D, (2008), The Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city, Indonesia, J. Earth Syst. Sci. 117, S2, November 2008, pp. 865–878.

Irsyam M., Asrurifak M., Hendriyawan D., Budiono B. (2010). Development of spectral hazard maps for a proposed revision of the Indonesian Seismic Building Code. Geomechanics and Geoengineering 5(1):35-47. DOI:10.1080/ 17486020903452725

I Wayan Sengara I. W., Irsyam M., Sidi I. D, Andri Mulia D. A., Asrurifak M., Hutabarat D. (2015). Development of earthquake risk-targeted ground motions for Indonesian Earthquake Resistance Building Code SNI 1726-2012. 12th International Conference on Applications of Statistics and Probability in Civil Engineering, ICASP12 Vancouver, Canada, July 12-15, 2015 1

Wood, R.L., Hutchinson, T.C. (2012) Effects of ground motion scaling on nonlinear higher mode building response, Earthquakes and Structures, Volume 3, Issue 6, 2012.

Carlson C. Pp., Zekkos D., McCormick J. P. (2014) Impact of time and frequency domain ground motion modification on the response of a SDOF system. Earthquakes and Structures, Volume 7, Issue 6, 2014, pp.1283-1301.

Bayati Z, Soltani M.(2016) Ground motion selection and scaling for seismic design of RC frames against collapse. Earthquakes and Structures, Volume 11, Issue 3, 2016, pp.445-459.

Pavel F., Vacareanu R. (2016) Scaling of ground motions from Vrancea (Romania) earthquakes. Earthquakes and Structures, Volume 11, Issue 3, 2016, pp.505-516.

Makrup, L. and Jamal A. U., (2016). The Earthquake Ground Motion and Response Spectra Design for Sleman, Yogyakarta, Indonesia with Probabilistic Seismic Hazard Analysis and Spectral Matching in Time Domain, American Journal of Civil Engineering, 4(6): 298-305

Makrup, L., and Muntafi, Y. (2016) Artificial Ground Motion for the Cities of Semarang and Solo Indonesia Generated Based on Probabilistic Seismic Hazard Analysis and Spectral Matching, EJGE (Electronic Journal of Geotechnical Engineering), Vol. 21, [2016] Bund. 21.

Makrup, L. (2017) Generating Design Ground Motion by Probabilistic Seismic Hazard Analysis and Code, EJGE (Electronic Journal of Geotechnical Engineering), Vol. 22, [2017] Bund. 5.

Nicolaou.A.S. (1998), A GIS Platform for Earthquake Risk Analysis. A dissertation submitted to the Faculty of the Graduate School of State University of New York at Buffalo USA in partial fulfillment of the requirement for the degree of Doctor of Philosophy, August.

Wood, R.L., Hutchinson, T.C. (2012) Effects of ground motion scaling on nonlinear higher mode building response, Earthquakes and Structures, Volume 3, Issue 6, 2012, pp.869-887

Artati H.K., 2023, Deterministic seismic hazard analysis to determine liquefaction potential due to earthquake, Civil Engineering Journal Vol. 9, No. 05, May, 2023.

Tanjung, M. I. (2017). Screening Analysis Stabilitas Lereng Bendungan Urugan Akibat Gempa di Indonesia. Jurnal Teknik Hidraulik Vol. 8 No.1, Juni 2017, 193-204.

Nicolaou.A.S. (1998), A GIS Platform for Earthquake Risk Analysis. A dissertation submitted to the Faculty of the Graduate School of State University of New York at Buffalo USA in partial fulfillment of the requirement for the degree of Doctor of Philosophy, August.

Seed, H. B. and Idriss, I. M.(1982), Ground motions and soil liquefaction during earth-quakes, Berkeley, CA, Earthquake Engineering Research Institute Monograph. Belum dicari dan blm ada pembahasan di atas

SNI 1726 (2019), Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung Dan Non Gedung, Badan Standrisasi Nasional, Jakarta.