UPDATING OF SURAKARTA SEISMIC SITE CLASS MAP 
BASED ON STANDARD PENETRATION TEST

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ABSTRACT

Surakarta is one of the cities in Java island with a high population growth rate, triggering the increase in the construction, especially for high-rise buildings. The city is close to several earthquake sources, causing a high level of seismic hazard. One of the main parameters of earthquake resistant building design is the value of peak ground acceleration at surface level. It is obtained by multiplying the peak ground acceleration in the bedrock by a multiplier factor that depends on the site class conditions of the location. A previous study has been conducted in 2015 using 32 boreholes indicating that around 19.5% of Surakarta area is classified as SC (hard soil), and 80.5% of the rest is SD (medium soil). To increase the accuracy, another 31 additional boreholes data are adopted. The new result shows that Surakarta is divided into three different seismic site class. Around 4.80% the area is classified as SC (hard soil), 94.50% is SD (medium soil), and 0.70% is SE (soft soil). The southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a SE (soft soil) seismic site class.

Keywords: Seismic site class map, updating.

INTRODUCTION

Java island is one of the islands in Indonesia, which is very close to the earthquake source. The study conducted by Tim Revisi Peta Gempa 2010 indicated that there are 10 major faults in Java (Irsyam, 2010). Further research was carried out by PusGeN to update the 2010 Indonesia hazard map. It was found that there are 16 new major sources of earthquake (faults) in Java (PusGeN, 2017). In addition to the source of the fault, Java is also relatively close to the subduction zone located in the south of Java island. The number of earthquake sources which are a threat to Java island makes it as a very high risk of seismicity.

The high risk of seismicity of Java prompts seismic studies for big cities in Java such as Jakarta (Aldiamar et al., 2013, and Asrurifak et al., 2013), Semarang (Jananda et al., 2014), etc. Surakarta is one of the main cities in this island with a high population growth rate of 1.23% per year which is much higher than the population growth of Central Java Province in 2018, which is only 0.68% per year (Disdukcapil Kota Surakarta, 2018). That increasing development in Surakarta especially in building construction needs the intensive study of seismic hazard of this city. Design of earthquake-resistant building construction in Indonesia currently refers to SNI 1726-2012 standard, which is referring to ASCE 07-2010 on design for minimum load for buildings and non-buildings. One of the main parameters of earthquake resistant buildings design is the value of peak ground acceleration at surface level. It is obtained by multiplying the peak ground acceleration in the bedrock by a multiplier factor that depends on the site class conditions of the location. The site condition is generally determined through Standard Penetration Test value (N_{SPT}) from the
bore hole, shear wave velocity ($V_s$), and undrained shear strength ($S_u$) of the soil layer at a thickness of 30 m from the surface.

Soil characterization for seismic analyses has been conducted in some cities in Java, such as Jakarta by Asrurifak et al. (2013), and Aldimar et al. (2013), Semarang by Jananda et al. (2014), Surakarta by Purwana, et al. (2005), Sa’adah et al. (2015), Warman et al. (2016), and Kurniawan (2019). The seismic site classification map has been developed by Warman (2015) using 32 boreholes. Compared to the size of Surakarta, the amount of these boreholes are too small and most of the data were flocked in the central. This paper presents the updating of the seismic site class map using SPT from another 32 additional boreholes data.

2. SPT AND SHEAR WAVE VELOCITY

Standard Penetration Test (SPT)

Standard penetration test is a test carried out to find out the dynamic resistance of the soil through obtaining the number of blows needed to insert a 300 mm standard vertical tube. The SPT testing is generally accompanied by the borehole test as which is the process refers to SNI 4153-2008 (BSN, 2008). The standard split spoon sampler is penetrated using a hammer load of 63.5 kg which is dropped repeatedly with a height of falling of 0.76 m. The testing process is divided into three stages with a thickness of 150 mm for each stage. The first stage ($N_1$) is recorded as a stand, while the second stage ($N_2$) and the third stage ($N_3$) are summed to obtain a standard penetration value ($N_{SPT}$) expressed in blows/0.3 m (BSN, 2008). The scheme for each step of the $N_{SPT}$ test can be seen in Figure 1.

![Figure 1. Standard penetration testing stage (BSN, 2008)](image)

The average values of $\bar{N}$, is calculated using the following equation:

$$\bar{N} = \frac{\sum_{i=1}^{n} d_i N_i}{\sum_{i=1}^{n} d_i}$$

(1)

where $N_i$ is standard penetration resistance in the i-th layer (blows/0.3 m), and $d_i$ is thickness of soil layer i (m)

As the average values of $\bar{N}$ is obtained, the classification of site class is determined using the criteria given by SNI 1726-2012 as shown in Table 1.

| Site Class     | $V_s$ (m/sec) | $\bar{N}$ or $\bar{N}_{um}$ | $S_u$ (kPa) |
|----------------|---------------|-----------------------------|-------------|
| SA (hard rock) | $>1500$       | N/A                         | N/A         |
| SB (rock)      | 750 to 1500   | N/A                         | N/A         |
| SC (hard soil, very dense, and soft rock) | 350 to 750 | $>50$                        | $\geq 100$  |
SD (medium soil) | 175 to 350 | 15 to 50 | 50 to 100
|<175 | <15 | <50
SE (soft soil) | Or each soil profile containing more than 3 m of soil with the following characteristics:
1. Plasticity index, \( PI > 20 \),
2. Water content, \( w \geq 40\% \),
3. Non-flowing shear strength, \( \bar{S}u < 25 \text{kPa} \)
SF (special soil requiring specific geotechnical investigations and site-specific response analysis) | Each soil profile has one or more of the following characteristics:
- Vulnerable and potentially fail or collapse due to earthquake loads such as liquefaction easily, clay is very sensitive, the soil is weakly cemented
- Very organic clay and/or peat (thickness \( H > 3 \text{ m} \))
- Clays with very high plasticity (thickness \( H > 7.5 \text{ m} \), with plasticity index \( PI > 75\% \))
- Soft/half firm clay layer with a thickness \( H > 35 \text{ m} \) and \( Su < 50 \text{kPa} \).

Note: N/A = cannot be used

Shear Wave Velocity (\( V_S \))

Shear wave velocity (\( V_S \)) is the main parameter used in determining the earthquake site class for a particular area. The value of \( V_S \) is also used as an initial reference to the problem of strains in seismic loading. Generally, \( V_S \) values can be obtained through the downhole test process, which is a geophysical test using direct seismic waves in the form of P-waves and S-waves to determine the character of subsurface layers (Kramer, 1996). In the case of the test is unavailable, the \( V_S \) values can be obtained through empirical correlation from SPT data as shown in Table 2.

| Reference | Correlations \( V_S \) (m/s) | Soil Sample |
|-----------|-------------------------------|-------------|
| (Ohta & Goto, 1978) | \( V_S = 85.3(N_{SPT})^{0.341} \) | Clay and Sand (Japan) |
| (Imai & Tenouchi, 1982) | \( V_S = 96.9(N_{SPT})^{0.314} \) | Clay and Sand (Japan) |

3. METHODOLOGY

The aim of this study is to develop the seismic site class map using \( N_{SPT} \) data. A previous study has been conducted using 32 boreholes, whereas in this study another 31 additional boreholes are utilized. All data are taken from a database in Soil Mechanics Laboratory, UNS. The process of data sorting was carried out to obtain required criteria for seismic analyses, such as the minimum 30 m of boreholes depth, and specified coordinate of boreholes. Due to the data of \( V_S \) is unavailable in the database, the \( V_S \) value for each layer and each borehole are correlated from \( N_{SPT} \) using the equation in the Table 2. Seismic site class is then determined using Table 1 for each borehole. The last step is plotting the result into the map.

4. RESULT AND DISCUSSION

Figure 2 shows the distribution of boreholes adapted from a previous study (Warman et al., 2015). Another 31 additional boreholes data (year 2015-2019) are plotted on the map as shown in Figure 3. Even though most of the new additional data are flocked in the central (business district), some blank spots in the north and south has been filled with the new ones.
The values of $N_\theta$ and $V_\theta$ for each borehole point are calculated based on equation 1 and equation in the Table 2. The results are then plotted on the map using QGIS 3.4.8 as shown in Figure 4 and 5 respectively. Figure 4 shows the distribution of hard soil with the high $N_\theta$ values (> 50) are found in Jebres subdistrict, the eastern part of Surakarta. The soft soil layer with the low of $N_\theta$ values (<15) are found along the border between Serengan subdistrict and Laweyan subdistrict. Figure 5 shows that the highest $V_\theta$ value of Surakarta with a range of 350 m/s to 380 m/s is found in the northern part of Surakarta, especially in the northern side of Jebres subdistrict and the northern side of Banjarsari subdistrict which is the border with Karanganyar district. It is seen from both figures that there is some difference of the seismic site classes area between direct $N_{SPT}$ and correlated $Vs$. However, it is indicated that Surakarta has 3 areas with different seismic site class, i.e. SC, SD, and SE.
Figure 4. $\bar{\alpha}$ distribution map of Surakarta 2019

Figure 5. $V_s$ distribution map of Surakarta 2019

Figure 6 shows the map of Surakarta seismic site class from a previous study (Warman, et al., 2015). Based on their study, Surakarta was divided into 2 seismic classes, i.e. $SC$ which is found in most of Jebres subdistrict, and $SD$ which covers almost 80% of Surakarta. However, with the additional data of boreholes, there are some areas of Surakarta which are classified as soft soil ($SE$) as shown in Figure 7. It is shown that that $SD$ site class (medium soil) is dominating Surakarta with the percentage of 94.50% (the northern side of the Jebres subdistrict area and a small portion of the border between Banjarsari subdistrict, Laweyan subdistrict, and Serengan subdistrict). Some area of the north side of Jebres subdistrict has an $SC$ (hard soil) seismic site class with a percentage of the area of 4.80%, while the border between Banjarsari, Laweyan, and Serengan subdistricts has a $SE$ (soft soil) seismic site class with a percentage of the area of 0.70%. It can be concluded that southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a $SE$ (soft soil) earthquake site class.
5. CONCLUSION

Previous studies indicated that Surakarta was divided into two seismic site classes; 19.5% of SC (hard soil) and 80.5% of SD (medium soil). A recent study indicates that there are some areas in Surakarta with soft soil layer (SE). Surakarta is divided into three site classes; 4.80% SC (hard soil), 94.50% SD (medium soil), and 0.7% SE (soft soil). The southern part of Surakarta has a higher level of vulnerability to earthquakes, especially in the border area between Banjarsari, Laweyan, and Serengan subdistricts which have a SE (soft soil) seismic site class.
REFERENCES

Aldiamar, F., dkk. (2013). “Kajian Awal Kelas Situs untuk Perencanaan Ketahanan Gempa Struktur Bangunan Gedung di DKI Jakarta”. Jurnal Permukiman, Volume 8, Halaman 108-114.

American Society of Civil Engineers (ASCE). (2010). Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, No. 7, ISBN 978-0-7844-1115-5.

Asrurifak, M. dkk. (2013). “Pengembangan Peta Klasifikasi Tanah dan Kedalaman Batuan Dasar untuk Menunjang Pembuatan Peta Mikrozonasi Jakarta dengan Menggunakan Mikrotremor Array”. HATTI 17th Annual Scientific Meeting, Halaman 67-72.

Badan Standardisasi Nasional. (2008). Cara Uji Penetrasi Lapangan dengan SPT. SNI 4153:2008, Jakarta.

Badan Standardisasi Nasional. (2012). Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung dan Non Gedung. SNI 1726:2012, Jakarta.

Imai, T., & Tenouchi, K. (1982). “Correlation of N-value with S-Wave Velocity and Shear Modulus”. Second Europe Symposium on Penetration Testing, Amsterdam: The Netherlands, Page 67-72.

Jananda, A. S., dkk. (2014). “Pengembangan Peta Kecepatan Gelombang Geser dan Peta Tahanan Penetrapan Standar di Semarang”. JURNAL KARYA TEKNIK SIPIL, Volume 3, Halaman 167-176.

Kurniawan, M. F., Koesuma, S., Legowo, B. (2019). “Vs30 Mapping and Site Classification in Surakarta City Based on Multichannel Analysis of Surface Waves Method”. Journal of Physics: Conference Series, Volume 1204, Conference 1.

Kramer, S., L. (1996). Geotechnical Earthquake Engineering. Prentice Hall, New Jersey.

Ohta, Y., & Goto, N. (1978). “Empirical Shear Wave Velocity Equation in Terms of Characteristic Soil Indexes”. Earthquake Engineering and Structural Dynamic, Volume 6, Page 167-187.

Purwana, Y. M., Saido, A. P., Maula, M. A. (2005). “Mapping of hard soil surface of surakarta based on CPT”. 3th International Conference of Geotechnical Engineering, Semarang, 3-4 Agustus 2005.

Sa’adah, U., Purwana, Y. M., Djarwanti, N. (2015). “Analisis risiko Gempa di Kota Surakarta dengan Pendekatan Metode Gumbel”. e-Jurnal MATRIKS TEKNIK SIPIL, Maret 2015, Halaman 30-35.

Warman, R. S., Purwana Y. M., Djarwanti, N. (2015). “The Study on Determination of Seismic Site Class Map of Surakarta”. 10th Indonesian Geotechnical Conference and 19th Annual Scientific Meeting, Jakarta, 14-25 November 2015, Page 207-212.

Warman, R. S., Purwana, Y. M., Djarwanti, N. (2016). “Profil Perkuasaan Tanah Keras Kota Surakarta Sebagai Informasi Pradesain Pondasi”. e-Jurnal MATRIKS TEKNIK SIPIL, Maret 2016, Halaman 83-91.