The Potential Liquefaction in Yogyakarta and Bantul

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Abstract-The phenomenon of liquefaction occured in Yogyakarta at the massive earthquake on May 27th, 2006. This phenomenon may be occur again because of the geological and seismic conditions in Yogyakarta that support the occurrence of liquefaction. This research aims to determine the level of liquefaction potential in Yogyakarta especially the central of Yogyakarta and Bantul. Analysis of Liquefaction potential use Youd method. The results of soil investigation shows that the type of soil in the research area is uniformly graded sand. The depth of the ground water level in October 2015 in the research area around 0,8-13,4 meters. The Attenuation function of Crouse-Mc Guire produce PGA largest value-which is about 0,23g-0,56g. The potential liquefaction in Yogyakarta is about 0 – 2,06 (very low) and Bantul is about 0 – 48. Watu is the highest potential liquefaction in Bantul.

***Keywords*:** earthquake, liquefaction, LPI

1. Introduction

Special Region of Yogyakarta has experienced liquefaction when a massive earthquake occured on May 27th, 2006. An earthquake with a strength of Mw=6.3 damages hundreds of homes, buildings, infrastructure and Adisucipto Airport runway. The majority of the damage due to liquefaction because there were liquefaction symptoms of sand boil, lateral spread, and ground settlement. The liquefaction occurred also because of the geological structure of the Special Region of Yogyakarta which most of it is derived from the uniform graded layer of sand. In addition, the seismic conditions in Special Region of Yogyakarta is very high because it is close to the subduction zone and has many active faults in the land. This research aims to determine the physical condition of soil, groundwater table and Peak Ground Acceleration (PGA), and determine the level of liquefaction potential by using Liquefaction Potential Index (LPI) in the city of Yogyakarta and Bantul Regency.

2. Literature Review

2.1. Liquefaction

Liquefaction is a losing process of shear strength of soils during an earthquake which resulted in the settlement of building, dam failures, landslides, and other disaster (Das, 1993). Day (2002) adds that the soil condition that is susceptible to liquefaction is the loose sand with shallow groundwater table. During the earthquake, the deployment of shear waves causes the loose sands compacted. As a result, the pore water pressure increased. The development of pore water pressure can change sand into liquid state. This condition causes the effective stress of soils becomes zero and the soil particles released from any restraint so it seems that the soil particles floating in the water (Ishihara, 1985). Kumar (2008) states that there are twelve dominant factors affecting liquefaction, they are ground shaking, groundwater table, soil type, relative density of soils, gradations of grain soil, origin of deposit formation, drainage, confined pressure, shape of soil particle, the age of the deposit, environmental history of the soil and building load.

2.2. Peak Ground Acceleration

Peak Ground Acceleration is the greatest ground vibration acceleration at a site due to earthquakes occurring over a period of time. PGA values are influenced by magnitude, location distance to earthquake source, earthquake mechanism and local soil conditions. PGA is a very influential parameter in liquefaction potential analysis. The greater the value of the PGA then the likelihood of greater liquefaction occurs. One method to predict peak land acceleration is to use the attenuation function. Some of the simple attenuation functions due to faecal (shallow crustal) and its movement mechanisms in Douglas (2011) are as follows:

Campbell (1990)

$$\ln(Y) = a + bM + d\ln[R + C_1 \exp(C_2 M)] + eF \quad (1)$$

where

Y = peak ground acceleration (g)

M = magnitue

R = the closest distance between the source of the earthquake and the point of view (km)

a = -2,245

b = 1,09

d = -1,89

C_1 = 0,361

C_2 = 0,576

e = 0,218

F = 0 for strike-slip

= 1 for reserve-slip

Crouse–Mc Guire (1996)

$$\ln(Y) = a + bM + d\ln[R + C_1 \exp(C_2 M)] + eF \quad (2)$$

where:

Y = peak ground acceleration (g)

M = magnitude

R = the closest distance between the source of the earthquake and the point of view (km)

a = -2,353903

b = 0,838847

C_1 = 0,305134

C_2 = 0,640249

d = -1,310188

e = -0,0151707

F = 0 for *strike-slip*

= 1 for *reverse-slip*

Sadigh (1997)

$$\ln(Y) = C_1 + C_2 M + C_3 M(8{,}5 - M)^{2,5} + C_4 \ln(r_{rup} + \exp(C_5 + C_6 M)) + C_7 \ln(r_{rup} + 2) \quad (3)$$

where:
Y = peak ground acceleration (g)
M = magnitude
R = the closest distance between the source of the earthquake and the point of view (km)
C_1 = -0,624
C_2 = 1 for M ≤ 6,5
= 1,1 for M > 6,5
C_3 = 0
C_4 = -2,1
C_5 = 1,29649 for M ≤ 6,5
= -0,48451 for M > 6,5
C_6 = 0,25 for M ≤ 6,5
= 0,524 for M > 6,5
C_7 = 0

2.3. Liquefaction Potential Index (LPI)

Liquefaction Potential Index (LPI) is the first method introduced by Iwasaki (1978) to predict the liquefaction potential level. The LPI analysis is calculated to a depth of 20 meters from the ground. The LPI formula proposed by Iwasaki (1984) is presented in Equation 4.

$$LPI = \int_{0}^{20m} F(z).w(z).dz \tag{4}$$

$$F(z) = 1 - FS \text{ for } FS < 1 \tag{4a}$$

$$F(z) = 0 \text{ for } FS \geq 1 \tag{4b}$$

$$w(z) = 10 - 0{,}5z \text{ for } z < 20 \text{ m} \tag{4c}$$

$$w(z) = 0 \text{ for } z \geq 20 \text{ m} \tag{4d}$$

where:
LPI = Liquefaction Potential Index
F(z) = the degree of damage of a layer in liquefaction analysis
w(z) = the weight factor of depth, if the deeper layers are terlikuifaksi then the effect on the damage on the surface of the soil smaller

2.4. Analysis Liquefaction Potential

2.4.1. *Cyclic Stress Ratio* (*CSR*)

$$CSR = 0{,}65 \frac{a_{\max}}{g} \frac{\sigma}{\sigma'} r_d \tag{5}$$

where:
a_{max} = ground peak acceleration (g)
g = gravitation (m/s^2)
σ = vertical total stress soil (kN/m^2)
σ' = vertical efective stress soil (kN/m^2)
r_d = *stress reduction koeficient*

2.4.2. *Cyclic Resistance Ratio* (*CRR*)

$$CRR_{7,5} = \frac{1}{34-(N_1)_{60cs}} + \frac{(N_1)_{60cs}}{135} + \frac{50}{[10.(N_1)_{60cs}+45]^2} - \frac{1}{200} \quad (6)$$

where:
CRR = *Cyclic Resistance Ratio*
$(N_1)_{60cs}$ = N-SPT corected *fines content*

2.4.3. Safety Factor (SF)

$$FS = \frac{CRR_{7,5}}{CSR} \times MSF \quad (7)$$

where:
FS = *Factor of Safety*
$CRR_{7,5}$ = *Cyclic Resistance Ratio*
CSR = *Cyclic Stress Ratio*
MSF = *faktor skala magnitude gempa*

3. Results

3.1. Soil Physical Condition

Based on geological map of Yogyakarta, the geological structure of Special Region of Yogyakarta, especially the city of Yogyakarta and Bantul regency is divided into five, they are volcanic sediment of young Merapi (Qmi), Sentolo Formation (Tmps), Semilir Formation (Tmse), Alluvium (Qa), and Nglanggran Formation (Tmn).

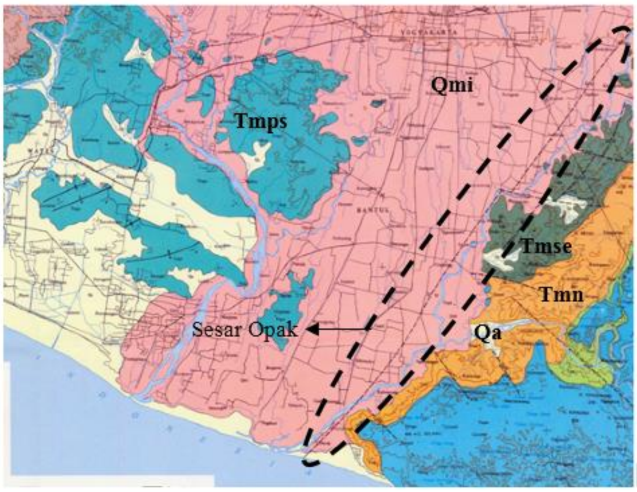

Fig 1. Geological map of Yogyakarta

Based on the field test, it is known that the soil type in the research location is mostly the sand that has medium density. The laboratory test suggests that soil layer is sand with the uniform gradation.

3.2. Groundwater Table

The liquefaction is influenced by the depth of the groundwater table in the region and also the several other parameters. Based on the survey results, the groundwater table on October 2015 ranging from 0.8 to 13.4 meter. The survey result of groundwater table can be seen in Figure 2.

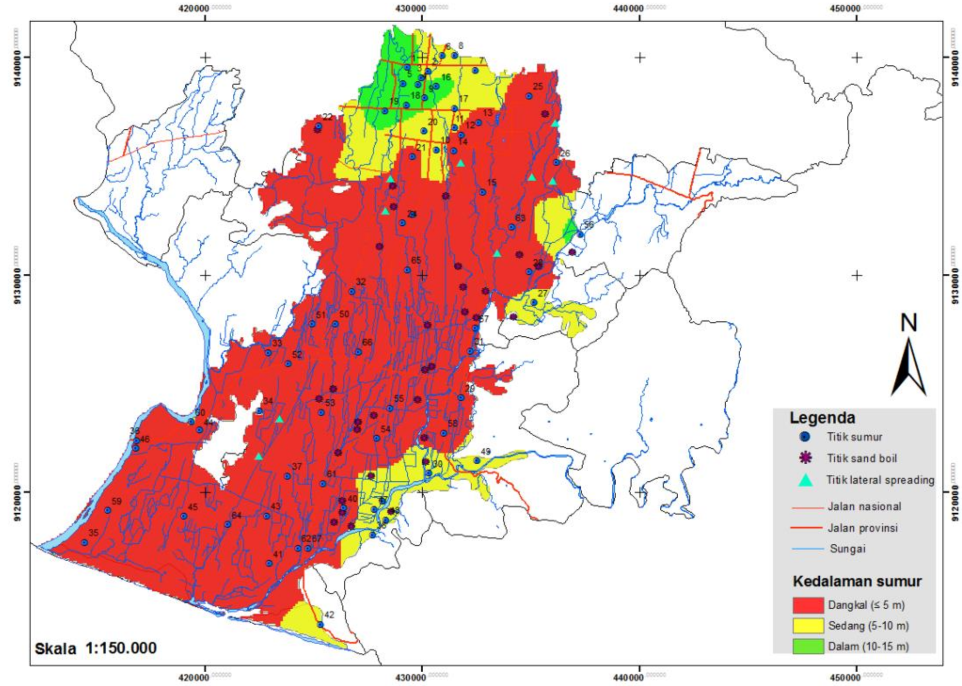

Fig 2. Map of groundwater table on October 2015 in the research area

Based on the lithology of groundwater basin in Yogyakarta-Sleman, the research area is included in Yogyakarta Formation and Sleman Formation. Both of these formations function as the layer of potential water carrier. These formations consist of sand sediment, gravel, silt, and clay.

3.3. Peak Ground Acceleration (PGA)

One of the parameters that the liquefaction occurred is the Peak Ground Acceleration (PGA). Based on PGA calculations, the attenuation function of Crouse-Mc Guire produces the greatest PGA value. The PGA epicenter of USGS ranging from 0,23g to 0,56g. The PGA distribution of the research point according to USGS can be seen in Figure 4.2, while the PGA distribution according to BMKG can be seen in Figure 3.

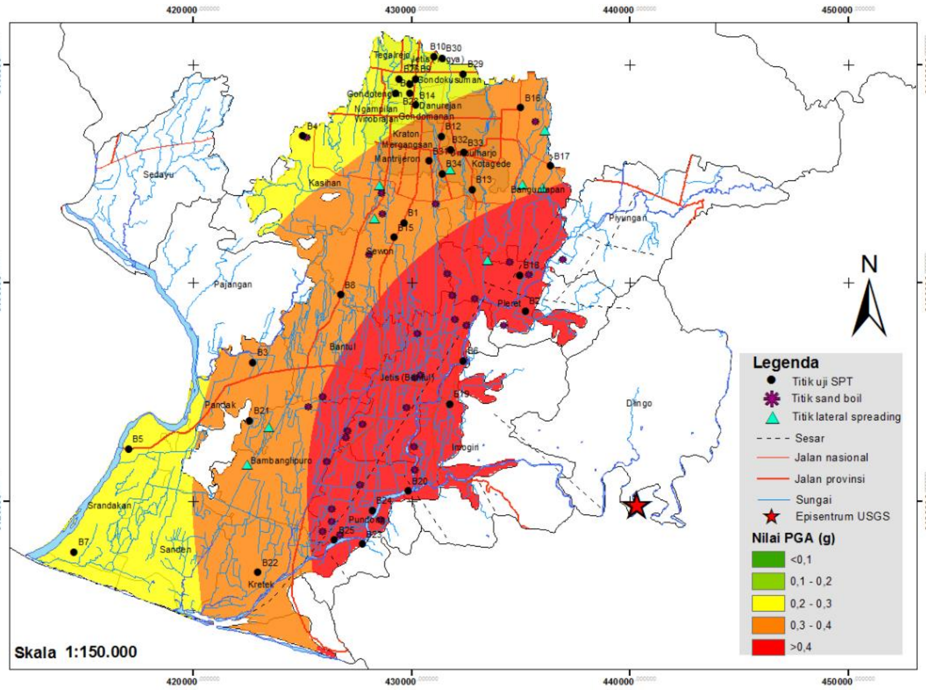

Fig 3. Map of PGA distribution based on USGS epicenter

3.4. Liquefaction Potential Index (LPI)

The analysis results of the liquefaction potential level based on LPI in the research area can be mapped to Figure 4.4. Based on Figure 4.4, the level of liquefaction potential in the research area is divided into four levels from very low to very high with value of LPI = 0-48. The liquefaction potential level is very low (LPI = 0) occurs in most of the city in Yogyakarta and Srandakan. Point B13 Giwangan and B34 Sorusutan have low level of liquefaction potential. The level of liquefaction potential in these two points can turn out to be higher if the groundwater table at that point is about 2 meters. Based on the interview, the groundwater table at that point in rainy season can reach 1.5 meters.

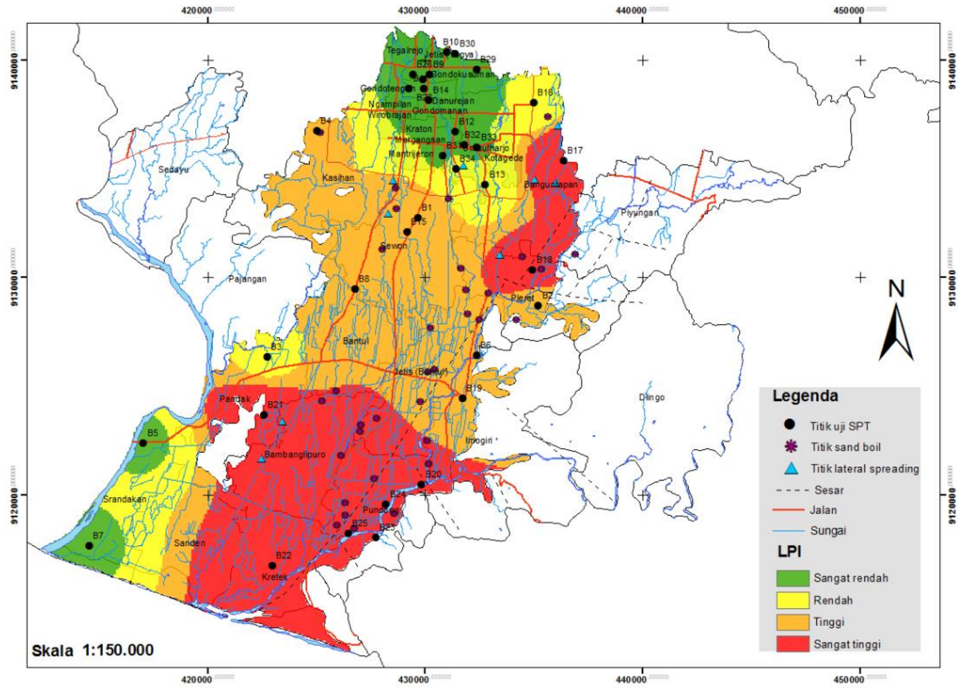

Fig 4. Map of Liquefaction Potential Index (LPI) in the research area

Besides those two points, the low level of liquefaction potential occurred in B3 Wijirejo and B16 Hardjolukito, both of them located in the regency of Bantul. The high liquefaction potential level is in the middle of the research area and very high level of liquefaction potential is in the eastern part of the research area. The layout of these two areas are in Bantul and along the Opak River.

4. Conclusions

The conclusion that can be drawn from this research is that the soil types in the research area was in the form of the uniform graded sand, the depth of the groundwater table on October 2015 was about 0.8 - 13.4 meters. The attenuation function of Crouse-Mc Guire produces the greatest PGA, for the USGS was 0,23g-0,56g. The level of liquefaction potential in the research area based on LPI was divided into very low to very high with the value of LPI = 0-48. The potential liquefaction in central of Yogyakarta is about 0 – 2,06 (very low) and Bantul is about 0 – 48. Watu is the highest potential liquefation in Bantul.

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