

Surabaya earthquake hazard soil assessment

Firman Syaifuddin^{1*}, Amien Widodo and¹, and Dwa Desa Warnana¹

Institut Teknologi Sepuluh Nopember Surabaya, Jl. Raya ITS, Keputih, Kec. Sukolilo, Kota SBY, Jawa Timur 60111

Abstract. The vulnerability of land in an area to earthquake ground motions is one of the factors causing damage caused by the earthquakes. The city of Surabaya, which is crossed by two active fault segments, needs an assessment to reduce the risk of being affected by an earthquake that might occur. The aims of this study are (1) to find out the distribution of Seismic Site Classes, (2) to know the distribution of the value of Seismic Amplification, and (3) to know the potential of liquefaction in the city of Surabaya. Surabaya city, which is geologically dominated by alluvium deposits, consists of soft soil (SE) and medium (SD) sites based on N-SPT30 and Vs30 data. The level of soil amplification against earthquakes ranging from 1 to 4. This occurs because the physical properties of the Surabaya City soil layer are dominated by alluvium deposits. Regions with more than 2 amplification values are located around the coastline on the North and East coasts of Surabaya City. Based on the potential liquefaction index value, Surabaya City is included in the region with a high potential for liquefaction with a potential liquefaction index value of more than 5.

1 Introduction

Surabaya is the second largest city in Indonesia, which has an area of 33,048 ha, of which 60.17% of the area is in the form of built-in areas and the population is approximately 3 million (BAPPEKO Surabaya, 2010). The city of Surabaya continues to develop dynamically as one of the complex regional and national centers (BAPPEKO Surabaya, 2010). The development of a good city is made by considering the conditions under the surface of the earth. Geological structure and geomorphological conditions need to be considered in connection with the potential for disasters and the mineral and mining resource content in the city area, which is beneficial for the development of the city (Daryono et al., 2009; Nakamura et al., 2000). Tectonic activity on the surface of the earth can be one of the causes of geological natural disasters, as is the case with volcanic activity beneath the surface of the earth which may also reach the surface (Irsyam et al., 2012; Soehaimi, 2008). One of the factors that determines the magnitude of the potential hazard of geological disasters is the physical nature of rocks near the surface. Geologically, Surabaya, 80% of its territory is a young alluvial sediment basin resulting from sea and river deposits, tuffs and sandstone, and the remainder are low hills formed by weathered soil from tertiary / old rocks. Regions with geological conditions like this have more significant potential for the effects of the intensity of ground vibrations due to amplification. (Soekardi, 1992).

The National Earthquake Study Center found that the location of Surabaya is geographically located on a fault, which is estimated to be still active and is presumably one day likely to cause a large earthquake in Surabaya. The fault is the Kendeng fault and the Waru fault. Kendeng fault crosses the center of Surabaya and moves 0.1 mm / year, whereas in the Waru area, Sidoarjo, there is a Waru fault that moves at 0.5mm / year. The fault splits Surabaya into two parts, namely north and south with an estimated maximum magnitude of 6.5. (PusGen, 2017). So, it is necessary to do a study and analysis of geology and geophysics that can provide scientific information about the earth, the following structure, the phenomena that occur, and its relation to the benefits for development in the city of Surabaya. In addition, it is necessary to analyze seismic hazard to predict ground motion and potential damage caused by the earthquake. So that this research is expected to be used as material for consideration of disaster mitigation, building structure design and spatial planning.

2 Geological Setting

Geologically, the city of Surabaya was formed by sedimentary rocks that were Miocene to Pliocene. These sedimentary rocks are part of the Kendeng lane with Sonde, Lidah, Pucangan and Kabuh formations. The basic rock for the city of Surabaya is the formation of Tongue, which is Pliocene (pre-tertiary). This formation is at a depth of 250 - 300 meters. Based on the geological map of Surabaya

* Corresponding author: firmonsyaifuddinakbar@gmail.com

and Sapulu, the Surabaya area is an area with geological conditions in the form of alluvial deposits and sandstone sediments in the form of limestone and clay (Sukardi, 1992). The city of Surabaya is the dominant lowland area, which ranges from 80% to alluvial deposits and the rest is low hills formed by weathered soil from tertiary / old rocks. According to Sukardi (1992) the Surabaya area consists of the following geological units. The Alluvium is in the form of gravel, sand, clay, and local fossil shell fragments. The Kabuh Formation is in the form of Sandstone, local gravel, light gray, coarse grained, aquatic structure, and criss-cross, conglomerate, poorly divided, open-packed, structured layers. Lower Pucangan Formation: layered tuffaceous sandstones, both with conglomerates and clay stones, rich in fossils of mollusks and plankton. The upper part: well-tufted sandstones, generally with water structures and silangsiur. Tongue Formation in the form of blue claystone, local blackish, springy, solid and hard when dry, fossil poor; thin claystone lens (Figure 1).

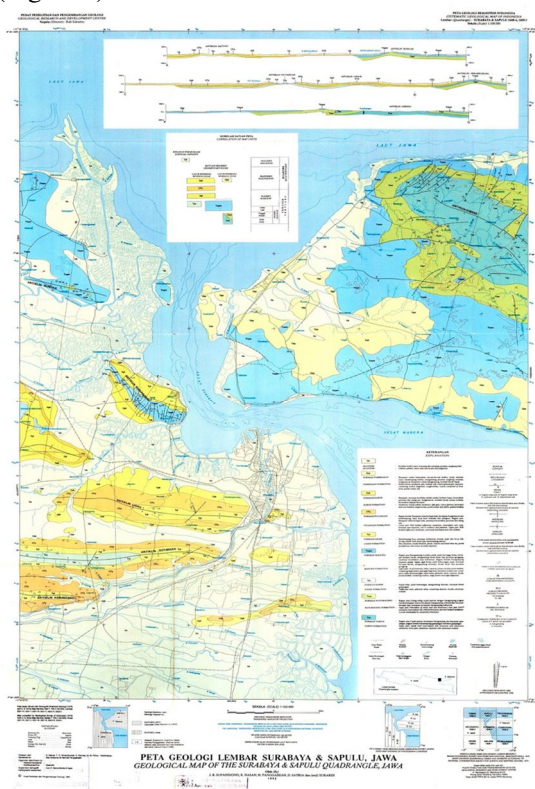


Fig. 1 Surabaya Sapuluh Geological Sheet (PPPG, 1992).

Geographically, Surabaya is in two faults, which are estimated to be still active. The fault is the Kendeng fault and the Waru fault with magnitude 6.5. The Kendeng fault crosses the center of Surabaya and moves 0.05 mm / year, whereas in Waru, Sidoarjo, there is a moving Waru

fault of 0.05 mm/year (PUSGEN, 2017). The movement of the Kendeng fault and Waru fault is thought to occur due to the insistence of the Indo-Australian plate in the northern part of the Surabaya region. One of the interesting geological phenomena in Surabaya is a river bend in the area between the two anticlines that appears to have a shift in location. This is an indication of the existence of a fault that resulted in the river shifting unnaturally. The Kendeng fault is a fault zone that extends west-east from Central Java to the western part of East Java. This fault consists of a collection of blind faults that can be observed from the presence of Bouguer anomalies in this area (Hamilton, 1979). In the western part of the kendeng fault, it appears to connect into the Semarang and Baribis Fault systems. Medium-sized shallow earthquakes (M4-5) occur along this fault zone in recent years. Evidence of the movement of this fault can be observed with the presence of river terraces, which are raised along with the movement of faults in this area (Marliyani et al., 2016).

In addition to the Kendeng fault and Waru fault, Surabaya is close to several lines of faults. These faults are Lasem faults, Watu Kosek faults, Grindulu faults and Pasuruan faults. The Lasem fault is in the north of Surabaya city for 70km. The Watukosek fault is in the south of Surabaya, which stretches from Mojokerto to Madura for 30km. While, the Grindulu fault located on the south coast of Pacitan to Mojokerto along 50km (PUSGEN, 2017), so that Surabaya allows an earthquake to occur from these faults.

3 Methods

In the assessment of earthquake hazards caused by effects near the surface can utilize geotechnical data in the form of superficial information in the form of soundir values, N-SPT, and the Specific Gravity value of an area. Based on SNI 1726-2012 regarding "Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung " classification of soil types can be carried out based on the average N-SPT value of 30 meters, so that the distribution of Seismic Soil Site Classification is known. Classification of soil site classes other than grouped based on N-SPT 30 values can also be classified based on the value of shear wave velocity (V_s) on average to a depth of 30 meters. In this study, classification was conducted based on the two types of data averaged. V_s value is obtained from the results of the geophysical measurement method MASW (multi-channel Analysis of Surface Wave).

In addition to the classification of soil types in this study, the calculation of earthquake vibration amplification values was also carried out based on the calculation of contrast shear impedance between bedrock and overburden. In this study, the assumption of shear impedance values at depths of more than 30 meters is used as the base rock shear impedance value. The shear impedance value is the product of the multiplication value of the specific gravity value multiplied by the value V_s .

The liquefaction potential index is calculated based on the sondir and N-SPT values at all calculation points. The potential for liquefaction can be determined using the Liquefaction Potential Index (LPI). The definition of LPI, as defined by Iwasaki et al. (1978) is a method to characterize liquefaction hazard (Holzer et al., 2009). Though other definitions for LPI were proposed, redefining it could alter the interpretations and the significance of an LPI value. The LPI takes into account the thickness of the liquefiable layers and the factors of safety with respect to depth. In order to calculate the LPI, Iwasaki et al. (1978) assumed that the severity of liquefaction is related to the total thickness of the liquefied layers, the depth of these layers (proximity to the surface), and how much less the liquefaction factor of safety (FS) is to one. The FS is a measure of the soil's capacity to resist liquefaction during an earthquake (Holzer et al., 2009). The assessment was carried out using 350 data points, 12 SPT data locations, 10 specific gravity data points and 48 MASW data points.

3.1 Seismic Soil Site Classification

In determining the type of soil location analyzed for the spectra response design, it is necessary to conduct soil investigations so that the log drill data in the form of N-SPT values of the location of the land are reviewed, or conducting a seismic borehole test to obtain shear wave strength values. From these two results, it can be used to classify soil types or commonly known as site classification. Each region has different sites or types of land, so it is important to classify sites into several classes of sites.

The speed of an S wave is the speed of a wave that occurs near the surface of the ground. Experts argue that soil density only varies slightly according to depth, so that the S wave velocity is considered more appropriate as one of the criteria for soil categorization. The speed of shear waves also varies according to the depth of the soil, so experts agree to use the average wave velocity S up to 30 meters below the surface (Prawirodikromo W, 2012).

This VS30 value can be used to estimate earthquake hazards and determine earthquake resistant building standards. VS30 can be estimated using microtremor measurements and Multichannel Analysis of Surface Waves (MASW) techniques. In addition, it can be estimated based on surface geology and geomorphological conditions.

3.2 Seismic Soil Amplification

Damage to building structures due to the earthquake and the intensity of ground shaking during an earthquake are significantly affected by geological conditions and local soil conditions. Soft sedimentary rocks are known to strengthen soil movements during earthquakes and therefore, the average damage caused is more severe than hard layers (Tuladhar et al., 2004). This means that sedimentary rocks are amplification factors for earthquake waves. Modern cities built on soft sediments will easily suffer damage due to the amplification of earthquake waves. There are two reasons for the amplification of earthquake waves that can cause damage to buildings. First, there is a wave trapped in the soft layer (Tsutomu Sato, 2004), so that the wave occurs superposition between waves, if the wave has a relatively similar frequency, then the earthquake wave resonance process occurs. As a result of this resonance process, the waves are mutually reinforcing. Second, there are similarities in natural frequencies between local geology and buildings (Roser and Gosar, 2010). This will cause resonance in buildings and local soil, which results in stronger ground vibrations in buildings.

The amount of amplification can be estimated from the impedance contrast between bedrock and surface sediment (Roser and Gosar, 2010). In other words, the contrast of wave propagation parameters (density and speed) on bedrock and surface sediments. The greater the difference in parameters, the greater the wave propagation amplification value. Furthermore, (Oliviera et al., 2006) argues that the amplification value is influenced by variations in the geological formation, thickness and physical properties of soil and rock layers, bedrock depth and underground water surface and subsurface structure surface.

In the classification of Amplification According (Marijiyono, 2010), it mentioned that the amplification is directly proportional to the value of the horizontal and vertical spectral ratio (H / V). The amplification value can increase if the rock has undergone deformation (weathering, folding or friction), which changes the physical properties of the rock. In the same rock, the amplification value

can vary according to the level of deformation and weathering of the rock body.

3.3 Liquefaction Potential Index

Liquefaction in the soil layer is influenced by the nature of soil engineering, geological environmental conditions and earthquake characteristics. Several factors that must be considered include grain size, groundwater level and maximum ground vibration acceleration (Seed and Idriss, 1971). The coastal areas along the western coast of Sumatra, the west coast - south of Java and southern Bali in several cities such as Banda Aceh, Padang, Bengkulu, Anyer, Cilacap, and southern Denpasar are an exposure to alluvium deposits, delta deposits, coastal embankment, fluvatile, swamp and lagoon. The geology of this area is characterized by Holocene coastal plain deposits, which faces open sea deposits in some places restricted by grabens in the form of faults that travel almost northwest- southeast. This quarter sediment is characterized by the repetition of sand units, which are quite dominant with grain sizes ranging from fine to coarse with inserts of silt and clay. The depth of the deposit is varied from depth - 4 meters to depth - 150 meters or more. While Jogjakarta and Solok are exposure to alluvial deposits in the Opak Fault zone (Wartono et al., 1977) and Semangko faults (Gafoer et al., 1992).

Therefore, a study of the potential hazard of liquefaction caused by earthquakes is needed in an effort to provide information on the coverage of areas vulnerable to liquefaction and whether the vulnerable areas are in the process of reconstruction or reconstruction, so that mitigation efforts to reduce the risk of liquefaction can be carried out in accordance with the level of vulnerability of liquefaction in each region. To be able to predict and mitigate the hazards of liquefaction, the knowledge about subsurface geological conditions and potential hazards of liquefaction in an area is needed.

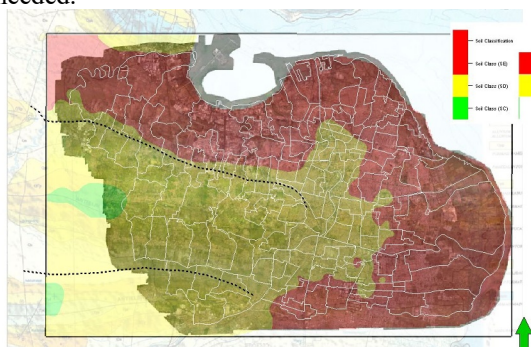


Fig. 3. Seismic Soil Site Class maps based on N-SPT values and an average of up to 30 m.

4 Result and Discussion

N-SPT30 is an N-SPT value averaged to a depth of 30 m from the surface. The value of N-SPT30 becomes one of the input variables in classifying classes of land sites based on SNI 1726-2012 regarding "Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung".

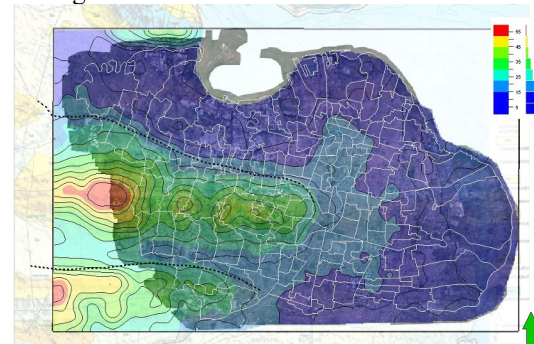


Fig. 2. N-SPT map averages to a depth of 30 m.

Figure 2 shows an N-SPT map averaged to a depth of 30 m. The maximum value on the map is 60, which is marked in red, while the minimum value is 2, which is marked in blue. In the picture shown in Figure 2, it is clear that N-SPT30 of less than 15 almost dominates the Surabaya City area, especially in the northern and East coast coastal areas. The value of N-SPT30 is more than 30 associated with the height of Tongue and Guyangan in the West and South of Surabaya City. Elevation of Tongue and Guyangan is geologically hard rock, while the part with N-SPT30 value less than 15 is alluvial sediment or river, which is quite extensive in the Surabaya City area. Based on SNI 1726-2012 concerning "Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung " N-SPT maps averaged to a depth of 30 m can be classified as a class of land sites. Figure 3 shows the Seismic Soil Site Class map based on N-SPT values averaging up to 30 m. In the area of Surabaya City is divided into 3 classes of land sites, namely Tanah Keras (SC) marked in green, Medium Land (SD) marked in yellow and Soft Ground (SE) marked with red, which dominates the City of Surabaya.

Figure 4 shows an N-SPT map averaged to a depth of 30 m. The value of Vs or shear wave velocity is obtained from MASW measurements (multichannel surface wave analysis) that have been carried out before by 42 Geophysics-ITS Teams covering the entire area of Surabaya City. Vs values range from 130 to 550 m / s, high Vs are marked in red while low Vs are marked in blue. Similar to the N-SPT value, the area of Surabaya City is

dominated by soil layers with low Vs which are geologically dominated by river sediment alluvium.

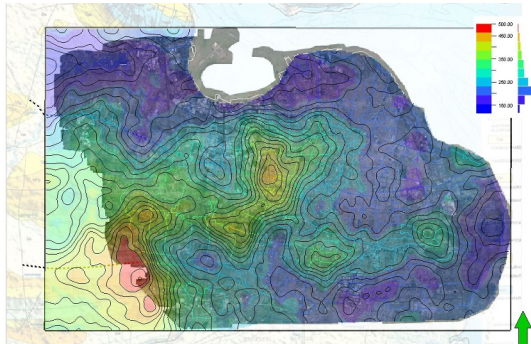


Fig. 4. Vs averages Map to a depth of 30 m.

In Figure 5, the Seismic Soil Site Class map based on Vs values averaged up to 30 m, classifications of soil site classes are grouped according to standards in SNI 1726-2012 on "Procedures for Planning Earthquake Resilience for Building Structure and Non Building". The Seismic Soil Site Class based on Vs30 value, Surabaya City area is dominated by the class of medium land sites (SC), namely land with a value of Vs30 between 175 to 350 m / s. As for the soil site class based on the N-SPT30 value, Hard Land (SC) is marked in green, Medium Land (SD) is marked in yellow and Soft Ground (SE) is marked in red.

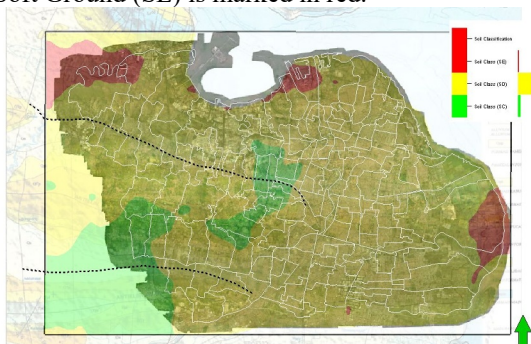


Fig. 5. Seismic Soil Site Class maps based on Vs values and an average of up to 30 m.

By utilizing the two classes of land sites, which are based on N-SPT30 and Vs30, a map of the average classes of land sites is made as shown in Figure 6, which produces a class map of land sites consisting of only two classes of land sites, namely Soft Soil (SE) and Medium Soil (SD). Classes of Soft Soil (SE) land sites are scattered around the coast of Utaran and East of Surabaya.

In addition to the N-SPT30 and Vs30 maps, in this study also conducted the mapping of the Sondir Specific Gravity value. For mapping, the alignment is carried out to a depth of 30 meters, as in N-SPT and the value of Vs.

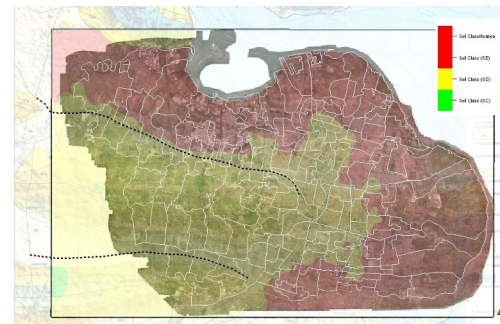


Fig. 6. Seismic Soil Site Class maps based on the average values of Vs30 and N-SPT30.

Figure 7 shows the Sondir Map averaging up to 30 m. The average Sondir value of 30 m ranges from 13 to 227, the low sondir value is marked in red while the high sondir value is marked in purple in figure 3.6 above.

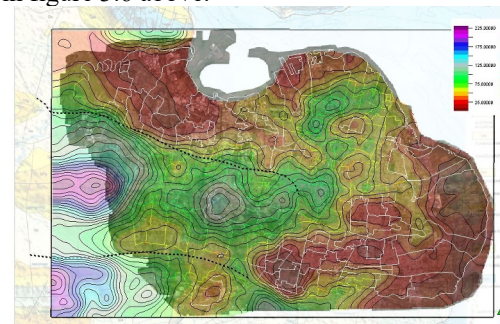


Fig. 7. The Sondir map of the average is up to 30 m.

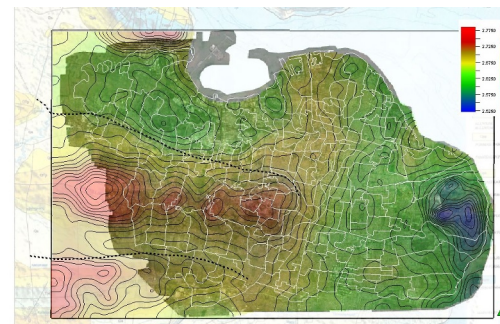


Fig. 8. Map of the Specific Gravity value averages up to 30 m

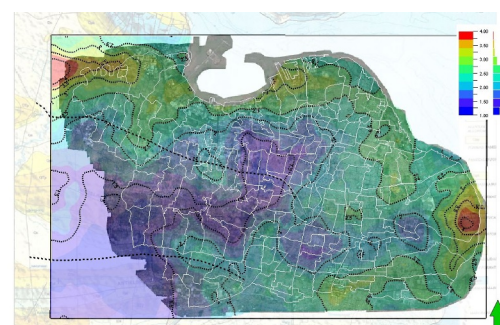


Fig. 9. Seismic Soil Amplification map.

Figure 8 shows a map of Specific gravity which is also carried out on average to a depth of 30 m. Specific gravity values range from 2.5 to 2.8. High Specific gravity values are marked in red and the Specific gravity values are marked in blue in Figure 8.

By utilizing Vs30 data and Specific gravity, a soil amplification map is made by comparing the shear wave impedance of 30 m to the maximum shear wave impedance in the study area, which is assumed to be the bedrock shear wave impedance. Figure 9 shows the distribution of soil amplification values ranging from 1 to 4.2. The high soil amplification value is marked in red and the low soil amplification value is marked in blue in Figure 9 below. The distribution of land amplification values is more than 2 over the North and East coast of Surabaya.

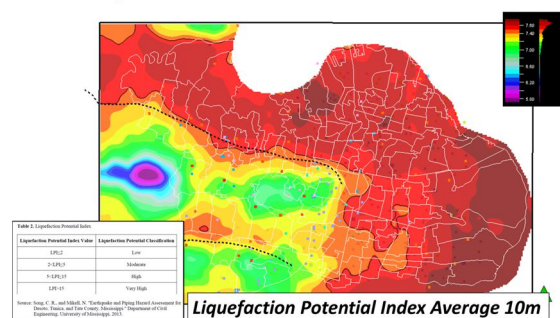


Fig. 10. Liquefaction Potential Index averaged depth of 10 m.

The liquefaction potential index is calculated based on the sondir and N-SPT values at all calculation points. In Figure 10, it is shown that the potential liquefaction index map is averaged to a depth of 10 meters. Based on the map at a depth of 10 m, the potential liquefaction index value is very small, so that to determine the overall function of the soil layer, it is averaged to a depth of 10 m. The potential liquefaction index value ranges from 5 to 8 at an average depth of 10 m, the red color indicates that the high potential liquefaction index in purple shows a low potential liquefaction index. Based on the average liquefaction potential index map to a depth of 10 m, the area that has the highest potential of liquefaction occurs if an earthquake occurs around the city of Surabaya is the East coast area of the city of Surabaya. This is possible because of the nature of the land, which is dominated by a layer of beach sand.

5 Conclusions

- The city of Surabaya, which is geologically dominated by alluvium deposits, consists of

classes of soft soil (SE) and medium (SD) sites based on N-SPT30 and Vs30 data in accordance with SNI 1726-2012 concerning "Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung " . Classes of soft land sites stretch parallel to the coastline on the north and east coasts of Surabaya.

- The Surabaya City area has a high level of soil amplification against earthquakes ranging from 1 to 4. This occurs because the physical properties of the Surabaya City soil layer are dominated by alluvium deposits. Regions with more than 2 amplification values are located around the coastline on the North and East coasts of Surabaya City.
- Based on the potential liquefaction potential index of the City of Surabaya is included in the region with high potential for liquefaction with a potential liquefaction index value of more than 5.

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