

# STUDY OF LOCAL SITE EFFECTS FOR SEISMIC VULNERABILITY MITIGATION BASED ON MICROTREMOR MEASUREMENTS IN THE NYIA AIRPORT AREA

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**ABSTRACT:** The Yogyakarta International Airport (NYIA) is situated on the coastal plain of Kulonprogo, underlain by alluvial deposits that increase susceptibility to local site effects during earthquakes. While previous studies in this area have examined peak ground acceleration (PGA) and liquefaction potential, research specifically addressing site effects has been limited. This study aims to evaluate site effects in the NYIA region by determining dominant frequency, amplification factor, and seismic vulnerability index. Microseismic measurements were conducted at 38 locations using a portable seismograph. The Horizontal-to-Vertical Spectral Ratio (HVSr) method was applied to process the microtremor data, and the results were mapped using GIS for microzonation. The analysis indicates that dominant frequencies in the NYIA area range from 0.51 to 10.36 Hz. Higher frequencies (>6.25 Hz) occur in the northern sector, adjacent to the Sentolo and Kebobotak Formations, whereas lower frequencies (0.51–2.5 Hz) are concentrated in areas with thicker alluvial deposits. Amplification factors vary between 1.11 and 5.82, with significant amplification (>3) observed in the airport zone and the alluvial plains of the Serang River. In contrast, lower amplification values (<2.9) appear near the geological boundaries formed by the Sentolo and Kebobotak Formations. The seismic vulnerability index ranges from 0.2 to 26, with the highest values (>19) located in the Serang River alluvial plains. The airport area exhibits a moderate vulnerability index of around 5, indicating a comparatively lower likelihood of experiencing severe site effects. Overall, the findings suggest that the NYIA zone experiences less surface-wave amplification than the surrounding Serang River alluvial region.

*Keywords: Yogyakarta International Airport (NYIA), Site effect, HVSr, Seismic vulnerability index*

## 1. INTRODUCTION

NYIA Airport has an area of 587.3 ha built with an ultimate capacity of 24 million passengers, a runway length dimension of 3,600 m, with a terminal area of 235,000 m<sup>2</sup>. NYIA Airport was built with the Aerotropolis concept which is equipped with rail access [1]. The Special Region of Yogyakarta, which is located to the south and southwest of Central Java, is served by the South Java line, which is developed and grows economically thanks in part to NYIA. Studying the potential for disasters in the area, including the potential for disasters from seismic hazards, is vital for the NYIA's important function. Due to the potential damage caused by such earthquakes, risk reduction and a priori seismic hazard assessment are required [2]. Geographically, subduction zones are relatively close to earthquake-prone regions [3]. NYIA Airport is an area with a high level of seismicity based on these conditions. NYIA has been designed to withstand the effects of earthquakes, but the buildings and environment around the airport have not been prepared to deal with the impact of strong earthquakes. Therefore,

it is necessary to conduct a local study of the site effect in the NYIA area and its surroundings. Reducing the risk of seismic hazards can be done in a good spatial manner as the first stage of disaster mitigation [4]. Microtremor is a geophysical method that can be used to map areas that may be damaged by seismic hazards or earthquakes [5]. For estimating local site effects, microtremor is very useful [6]. The constant shaking that comes from the ground is called microtremor [7]. Due to its relatively low cost and non-disruptive measurement environment, this method is often used. In addition, microtremor can be used easily in urban areas [8]. The HVSr (horizontal to vertical spectral ratio) method can be used to perform microtremor analysis. This method is a method that compares the spectrum of the horizontal component of the microtremor signal to the vertical component. Shaking is stronger in areas of low shear velocity or in thick sediments, and earthquake damage is generally greater in soft sediments than bedrock outcrops [9; 10; 11; 12]. Numerous researchers have conducted studies on NYIA. Previous research has focused on PGA studies and liquefaction [13; 14].

Research conducted has succeeded in mitigating disasters using the microtremor method in the city of Bandung [15]. The geology of the region, which is dominated by lake sediments, is one of the reasons magnifying seismic waves, according to the study's findings. Another study was also conducted by Setiawan et al. (2021), this research has succeeded in microzoning areas prone to seismic hazards in the northern coastal area of Kendal using the microtremor method. The results of this study indicate that areas with high seismic wave amplification potential are located around the coast and on the outskirts of large rivers. Based on previous studies, the microtremor method is appropriate for showing local site effects and mapping areas that have seismic hazard potential. The NYIA area is located on the South Coast of Kulonprogo with a coastal plain of the Alluvium Formation (Qa). Sedimentary material which is dominated by rocks, sand, silt and clay makes this area at risk of site effects when an earthquake [16; 17]. This was also conveyed in other studies which stated that damage due to earthquakes was generally greater in soft sediments than bedrock outcrops and in many cases site amplification or stronger shocks occurred in areas with low shear wave velocities or in thick sediments [18; 19]. The southern region of Daerah Istimewa Yogyakarta regency (DIY) is an area that is in a subduction zone, so earthquakes often occur in the southern

region of Daerah Istimewa Yogyakarta regency (DIY). A study based on the seismic hazard potential in the NYIA area should be carried out due to the area's significance. This study uses a microseismic approach to calculate the site effect in the NYIA area based on dominant frequency ( $f_0$ ), amplification factor ( $A_g$ ), and seismic vulnerability index ( $K_g$ ).

## 2. RESEARCH SIGNIFICANCE

This research aims to contribute to earthquake hazard mitigation, specifically in the NYIA area, with potential applications to other regions as well. The diverse geological formations within an area exhibit varying responses to seismic wave propagation. In addition to lithological factors, the tectonic dynamics surrounding NYIA are also a crucial consideration in geological studies of this area. Its proximity to the subduction zone makes it vulnerable to earthquakes caused by megathrust activity occurring along the Indo-Australian and Eurasian Plate boundary. Historically, DIY has experienced several major earthquakes originating from this subduction activity, including the 2006 Bantul earthquake, which had a magnitude of 6.3 Mw and caused significant infrastructure damage. Besides the earthquake hazard, the interaction between tectonic activity and the coastal environment also

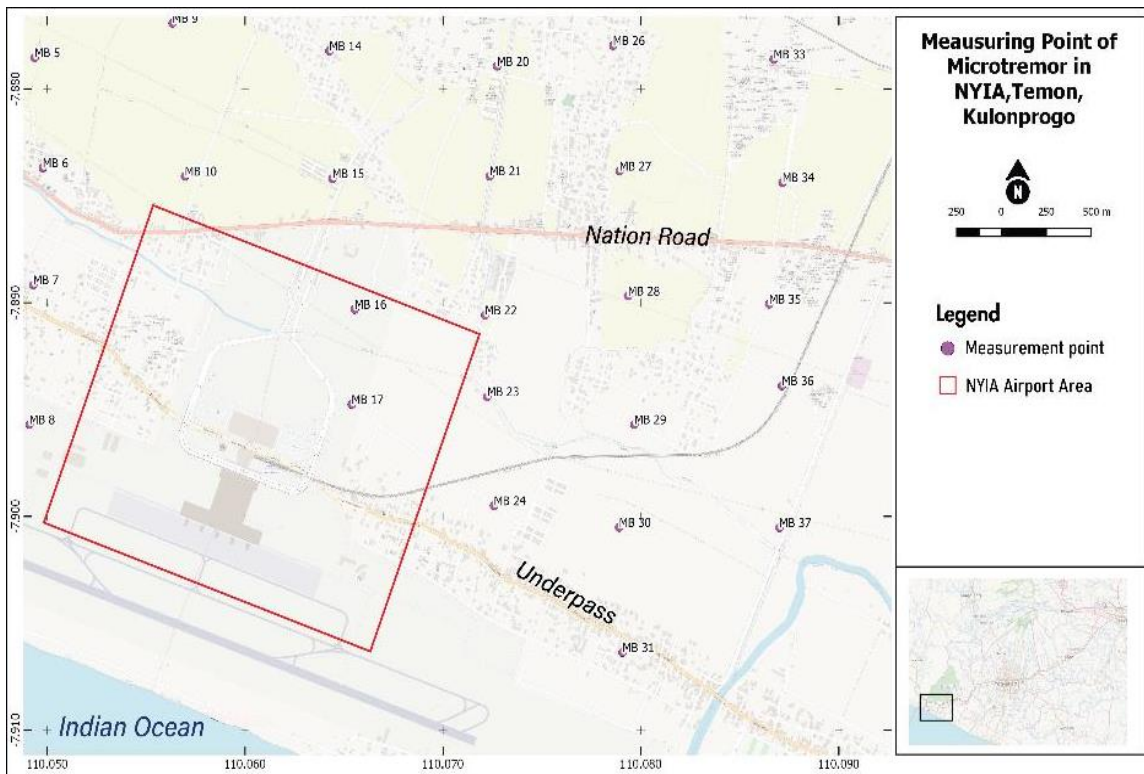


Fig.1 Location of microtremor measurement points at NYIA Yogyakarta Airport

poses a tsunami threat, which could have a direct impact on the NYIA vicinity. Therefore, disaster mitigation strategies, such as the development of earthquake-resistant building structures, tsunami early warning systems, and coastal environment management, are essential aspects of urban planning and regional development in this area.

### 3. METHODS

The research was conducted in the NYIA area, administratively located in Temon District, Kulonprogo Regency, Yogyakarta Special Region Province (DIY). NYIA which is located on latitude 7°52'12" S to 7°54'36" S and longitude 110°3'E to 110°5'24"E (Fig. 1). Measurement points using the grid method with intervals of  $\pm 1$  km, with 38 measurement points. The NYIA area is characterized by Alluvium Formation (Qa).

### 3.1 Equipment And Materials

Measurement using the microseismic method with portable seismograph equipment, geological compass, GPS, software geopsy and seismometer Guralp CMG-40TD with a flat response of 0.03 Hz to 50 Hz [20]. The low frequency of seismometers is expected to get a seismic response to depths of more than 100 meters. The SESAME European research project served as the foundation for the standard operational measurement equipment, which has a 30-minute measurement time for each point with sampling of frequency 100 Hz [21; 22]. Microtremor data is processed using the HVSr (horizontal to vertical spectral ratio) method using geopsy software. Single station microtremor data describes the ground vibration velocity in 3 components (north-south, west-east and vertical) in the time domain.

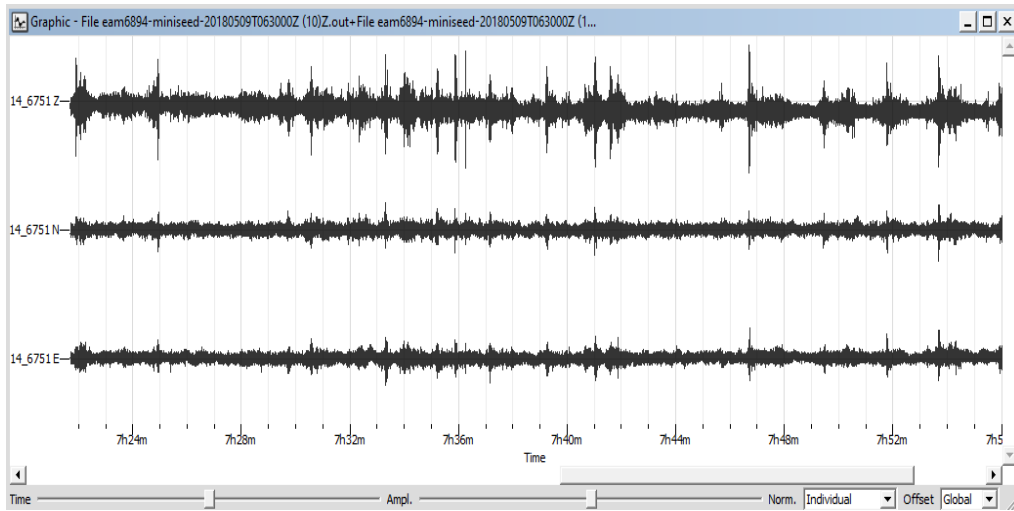


Fig.2 Example of raw data of 3 components single station microtremor with name MB 29

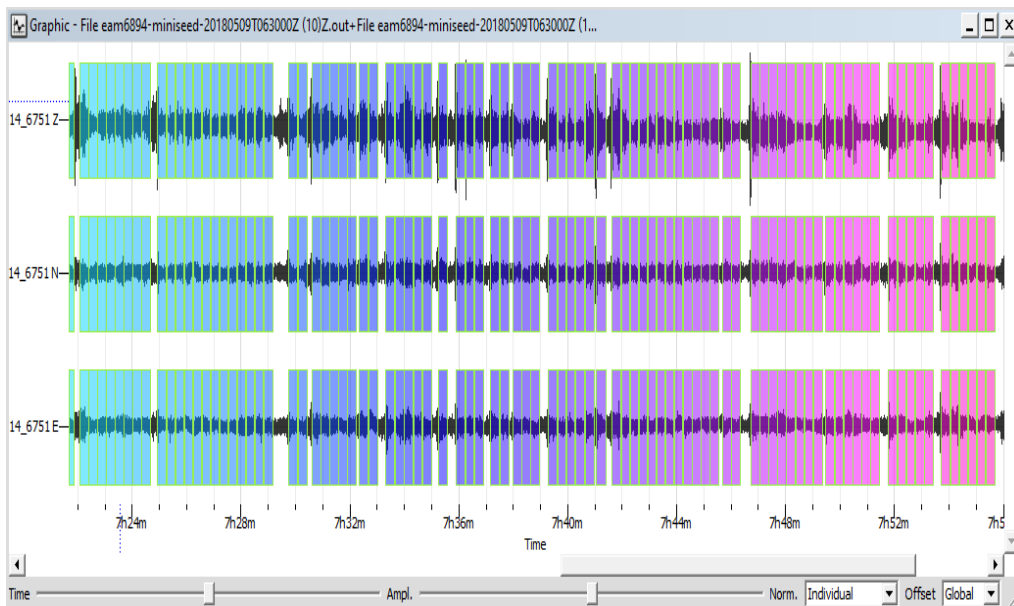


Fig.3 Windowing of single station 3 components microtremor data

The desired end result is a spectrum in the frequency domain obtained using the fourier transform in geopsy software.

### 3.2 Research Work Procedure

This research began with a literature study by looking for geological information on the study area. Then a research survey design was made as shown in Fig 1. Microtremor data collection was conducted directly in the research area. The microtremor measurement data was then processed by the HVSR (horizontal to vertical spectral ratio) method resulting HVSR curve. The HVSR curve has reliability criteria that refer to the standards made by the SESAME European Research Project. Following is how the HVSR equation yields the HV curve [23]:

$$HVSR = \frac{\sqrt{(A_{(N-S)}(f))^2 + ((A_{(W-E)}(f))^2}{A_{(V)}(f)} \quad (1)$$

Where:

HVSR = Horizontal to Vertical Ratio

$A_{((N - S))} (f)$  = Amplitude value of the North-South component of the frequency spectrum

$A_{((W - E))} (f)$  = Amplitude value of the West-East component of the frequency spectrum

$A_{((V))} (f)$  = Amplitude value of the vertical component of the frequency spectrum

### 3.3 Microtremor Processing Data

The results of microtremor signal recording are in the form of spectrum data in the time domain. The data is displayed in the form of raw data in geopsy software as shown in Fig 2. The first spectrum (Z) represents a microtremor record for the vertical component, which captures ground motion along the upward and downward axis. The middle spectrum (N) corresponds to the horizontal component in the North-South direction, indicating the movement of ground vibrations along this axis. Meanwhile, the bottom spectrum (E) represents the horizontal component in the East-West direction, capturing the oscillations in that plane. These three components together provide a comprehensive representation of ground motion and are essential in seismic analysis, especially in understanding the dynamic behavior of the subsurface.

To extract meaningful data from these waveforms, the windowing process is applied. Windowing, also known as signal pacing, is a technique used to segment the signal into smaller time intervals while preserving the integrity of its frequency content. This method is crucial for eliminating unwanted noise and focusing on specific portions of the waveform that are relevant for analysis. By selecting an appropriate window size, researchers can improve the signal-

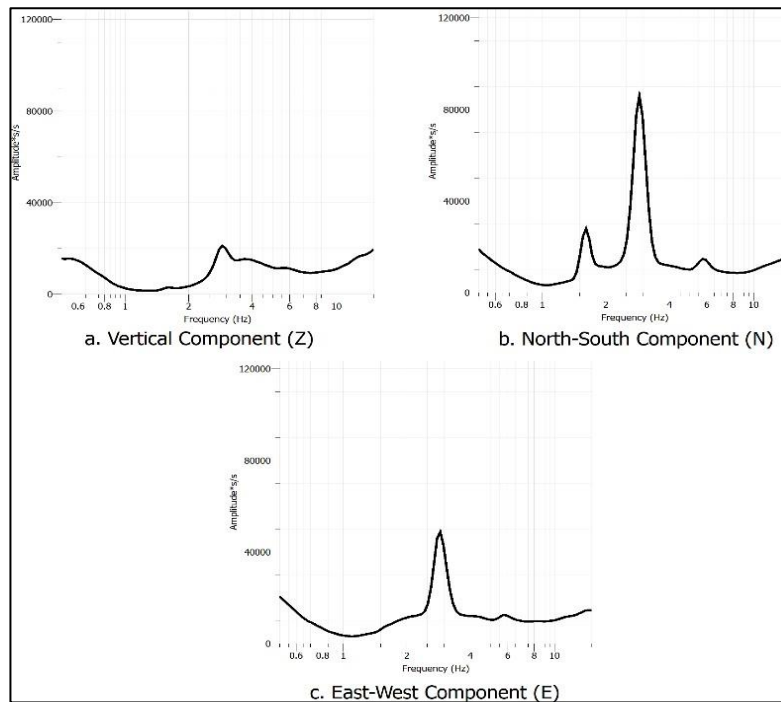


Fig.4 (a) Average spectrum of Vertical (Z) component, (b) Average spectrum of North- South (N) component, (c) Average spectrum of East-West (E) component

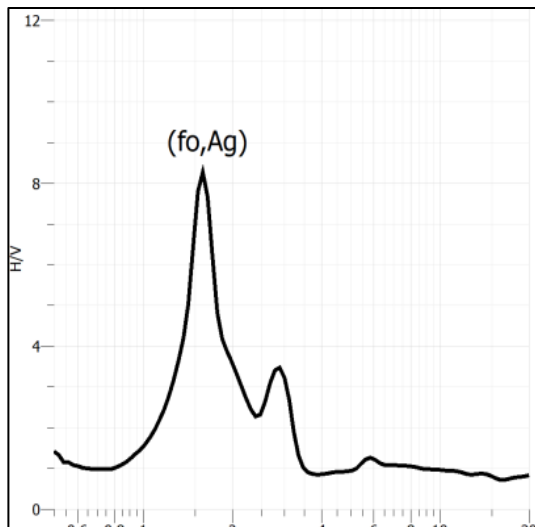


Fig.5 HVSR curve as a result of microseismic data processing

to-noise ratio (SNR) and enhance the accuracy of microtremor analysis. In this study, the selected signals are stationary signals, meaning that their statistical properties remain constant over time. This characteristic is important because stationary signals allow for more reliable spectral analysis, enabling the identification of dominant frequencies, peak amplitudes, and resonance effects in the subsurface. The time-domain representation of the signals in the figure provides insights into the amplitude variations and frequency content of the recorded microtremors. Sharp spikes in amplitude may indicate transient disturbances, while sustained oscillations reflect the resonance properties of the local geology.

The data in the window of each component will be Fourier transformed so that the average spectrum of each component is obtained as shown in Fig. 3. The resultant horizontal component consisting of north-south (N) component and east-west (E) component is divided by the vertical component using equation 1 to obtain the HVSR curve shown in Fig. 4. The HVSR curve that was produced to determine the dominant frequency value ( $f_0$ ) and amplification factor ( $A_g$ ). Fig. 5 is a HVSR curve of the result of microseismic data processing at the measuring point MB 29. All HVSR curves used have reliability criteria that refer to the standards made by the European Research Project. The reliability curve criteria used in this study are first, the peak frequency value of the HVSR curve ( $f_0$ ) must be greater than 10 divided by the window length ( $lw$ ) written as  $f_0 > 10/lw$ . Second, the number of significant cycles ( $nc$ ) must be greater than

200 written as  $nc > 200$ , where  $nc$  is obtained from multiplying  $lw$ ,  $f_0$ , and  $nw$ ,  $nw$  is the total number of windows used. Third, if the dominant frequency value ( $f_0$ ) is more than 0.5 Hz the standard deviation should be less than 2 ( $\sigma A(f) < 2$ ) for HVSR amplitude values in the range ( $0.5 f_0 < f < 2 f_0$ ), while if the frequency value is less than 0.5 Hz the standard deviation should be less than 3 ( $\sigma A(f) < 3$ ) for HVSR amplitude values in the range ( $0.5 f_0 < f < 2 f_0$ ).

The process of peaking the data was then carried out by selecting clearly visible peaks so as to obtain the dominant frequency ( $f_0$ ) and amplification ( $A_g$ ) values. In the case of small peaks that cause confusion in peaking, the researchers compared the results with adjacent measurements. The dominant frequency ( $f_0$ ) and amplification ( $A_g$ ) values were then mapped to find out how they were distributed.

Using the input parameter values for dominant frequency ( $f_0$ ) and amplification factor ( $A_g$ ), the seismic susceptibility index is produced using the following equation [23;24].

$$K_g = \frac{A_g^2}{f_0} \quad (2)$$

Where,  $K_g$  is the index of seismic susceptibility, The dominating frequency is  $f_0$ , and  $A_g$  is the amplification factor. The outcomes of the microseismic data processing are then carried out again for the microzonation of each parameter using GIS. The shear wave velocity at a depth of 30 meters below the surface is known as  $v_{s30}$ . For the purpose of establishing earthquake-resistant construction standards, the  $v_{s30}$  value can be employed. When developing earthquake-resistant structures, the  $v_{s30}$  value is used to classify rocks depending on the strength of seismic vibrations caused by local effects. Sediment thickness is related to the dominant frequency, the relationship between sediment thickness and dominant frequency can be known based on the rule of closed organa pipe. When the sediment thickness ( $H$ ) is  $\lambda/4$ , amplification is maximum at the resonant frequency or dominant frequency. The value of  $v_{s30}$  can be determined using the equation:

$$f_0 = \frac{v_{s30}}{4H} \quad (3)$$

where,  $H$  = Depth of sediment (m),  $v_{s30}$  = Shear wave velocity at a depth of 30 meters, and  $f_0$  = Dominant frequency (Hz)

The classification of rock types based on the average shear wave propagation speed to a depth of 30 meters ( $V_{s30}$ ) is shown in Table 1.

Table 1. Site Classification based on  $v_s$  value [25]

Site Class	$V_s$ (m/s)
SA (hard rock)	>1500
SB (rock)	750 – 1500
SC (hard, very compact soil, and soft rock)	350 – 750
SD (medium soil)	175 – 350
SE (soft soil)	<175

#### 4. RESULTS AND DISCUSSION

Microtremor measurements were collected in the NYIA airport area because seismic wave amplification due to local site effects is related to building damage [26]. Therefore, it is necessary to know the physical parameters related to the local site effect to overcome the damage caused by the disaster that will occur. Microtremor data in this study was collected directly. The data were processed using the Horizontal to Vertical Spectral Ratio (HVSr) method to assess the site effect. The results obtained from the HVSr curves represent the geological conditions of the study area in the form of dominant frequency parameters and amplification factors [27]. Each HVSr curve obtained from the data processing results is then analyzed whether it meets the reliability criteria or not.

##### 4.1 Microzonation of Dominant Frequency ( $f_0$ ) in the NYIA Region

Soil conditions and local geological characteristics significantly influence the

propagation of seismic waves, as demonstrated in various studies [29]. Soft soil, composed primarily of unconsolidated sediments, tends to amplify ground motion at low frequencies (high periods), making it more susceptible to seismic hazards. Conversely, hard soil or bedrock does not significantly amplify seismic waves, particularly at high frequencies (low periods), due to its greater rigidity and ability to dissipate energy. This fundamental difference in seismic response is crucial for site-specific earthquake risk assessments, particularly in regions such as the NYIA area, where the presence of alluvial deposits plays a dominant role in soil behavior during seismic events.

The results of the microtremor analysis are presented in the form of a microzonation map. The microzonation map was created using the interpolation kriging method, because this method considers spatial correlations in the interpolation process. The results of microtremor analysis in the NYIA region indicate that the variation in dominant frequency ( $f_0$ ) ranges from 0.51 to 10.36 Hz, with a significant portion of the airport area exhibiting  $f_0$  values lower than 2.5 Hz (Fig. 6). Based on the Kannai classification, this frequency range corresponds to soil type IV, which is characterized as an alluvial plain. This classification aligns well with the geological conditions of the southern coast of Kulonprogo, which predominantly consists of Alluvium Formation (Qa). Supporting evidence from Irzon (2018) confirms that the region is dominated by alluvial deposits composed of gravel, sand, silt, and clay, which are especially concentrated along major river channels and coastal plains [29]. The uniformity of dominant frequency distribution ( $f_0$ )

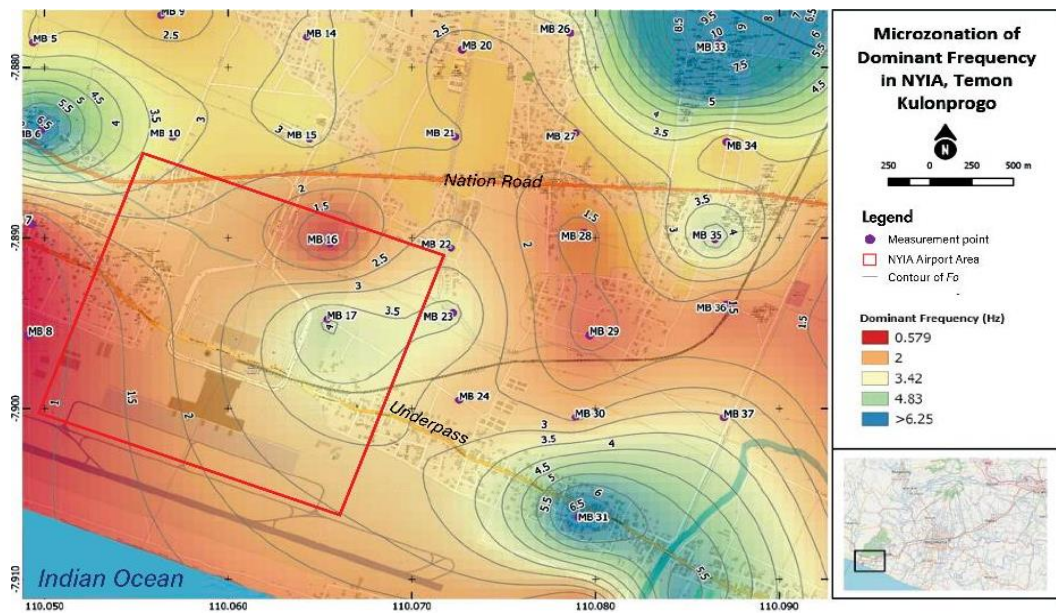


Fig.6 Microzonation of Dominant Frequency ( $f_0$ ) in the NYIA Kulonprogo Area

in the NYIA area further corroborates its correlation with underlying geological formations. Areas with low dominant frequency values (<2.5 Hz) correspond to thick sedimentary layers that form the southern coastal deposits, whereas higher frequencies (>6.25 Hz) are observed in the northern part of the region, where the bedrock formations of Sentolo (Tmps) and Kebobutak (Tmok) emerge. These high-frequency zones correspond to soil types I (the thickness of the surface sediment is very thin, dominated by hard rocks) and II (the thickness of the surface sediment is in the intermediate category of 5-10 meters), where the sediment layers are significantly thinner, thereby exhibiting greater resistance to ground motion amplification.

Dominant frequency represents the most consistent and prominent frequency within a given site, characterized by high amplitude values in microtremor recordings. Fig 6 illustrates the spatial distribution of dominant frequency ( $f_0$ ) across the NYIA area, where each measurement point has been mapped using contour interpolation. The color-coded representation in the figure provides a clear visual of frequency distribution patterns. The observed frequency distribution suggests that sediment thickness plays a crucial role in determining local seismic behavior. According to previous studies by Wibowo and Gunawan (2017), the Kulonprogo region consists of volcanic-derived soft materials, predominantly exhibiting a dominant frequency range between 1.04-1.50 Hz. This frequency range falls within the low-frequency category, which aligns well with the findings of this study, further reinforcing the characterization of the region as a seismically susceptible soft soil zone [30].

Furthermore, the relationship between dominant frequency and sediment thickness has been extensively documented in Nakamura (2000), where higher frequencies correspond to thinner sediment layers, while lower frequencies indicate thicker sediment deposits [25]. This principle directly supports the results of the current study, both quantitatively and qualitatively, reinforcing the significance of microtremor-based site characterization in earthquake hazard mitigation. The findings from this analysis are essential for seismic microzonation, which aims to classify and map areas based on their potential seismic amplification and ground motion response.

#### **4.2 Microzonation of Amplification Factor ( $A_g$ ) in the NYIA Region**

Amplification refers to the increase in wave amplitude that occurs when seismic waves travel through sedimentary layers, as reflected in the peak values of the Horizontal-to-Vertical Spectral

Ratio (HVSr) curves. The amplification factor quantifies how many times the wave amplitude is enhanced during an earthquake. The degree of amplification is primarily controlled by the impedance contrast between soft sedimentary deposits and underlying bedrock [31]. When seismic waves pass from a high-density medium (bedrock) into a lower-density medium (soft sedimentary deposits), they experience an increase in amplitude due to the difference in wave propagation velocity. This phenomenon is heavily influenced by local geological conditions, making it a crucial factor in earthquake hazard assessment and mitigation.

In the NYIA region, the amplification factor varies between 1.11 and 5.82, with higher amplification values (>6.0) concentrated around the airport area and the alluvial deposits of the Serang River. This pattern corresponds to the geological formations of the southern coast of Kulonprogo, which are dominated by the Alluvium Formation (Qa). The Alluvium Formation, composed of gravel, sand, silt, and clay, belongs to the sedimentary material category, which is known to increase seismic wave amplification during an earthquake [32]. Areas dominated by soft sediment tend to exhibit higher amplification effects, which can significantly intensify ground shaking, particularly in the event of strong seismic activity in DIY and its surrounding regions. The spatial distribution of the amplification factor in the NYIA area reveals a clear contrast between the northern and southern regions. The southern coastal region, which contains thick alluvial deposits, exhibits higher amplification values (>6.0), whereas the northern part of NYIA, which borders the Sentolo (Tmps) and Kebobutak (Tmok) Formations, has lower amplification values (<3.0), as illustrated in Fig 8. The northern NYIA area, being underlain by more compact and consolidated bedrock, is expected to have a smaller seismic wave amplification response compared to the southern region, where unconsolidated sediments dominate.

The magnitude of the amplification factor is visually represented in Fig 7, where high amplification zones are marked in red and orange and are predominantly located in the eastern and southern parts of the research area near the airport. These zones indicate significant wave amplification, making them potentially hazardous locations during seismic events. In contrast, low amplification zones are shown in blue and green, primarily found in the northern part of the study area, where bedrock formations provide greater structural stability against seismic waves. The classification of amplification factor magnitudes into various levels is based on previous research [26]. This classification is essential for identifying

areas that require seismic hazard mitigation measures such as soil improvement, seismic-resistant construction, and proper land-use planning. The results of this study further emphasize the need for site-specific engineering assessments in the NYIA area, particularly in high-amplification zones, where the potential for ground motion intensification is significantly higher.

### 4.3 Microzonation of the Seismic Susceptibility Index ( $K_g$ ) in the NYIA Area

The seismic vulnerability index ( $K_g$ ) is a crucial parameter that quantifies the susceptibility of soil and built structures to damage during an earthquake [24]. This index is directly influenced by the amplification factor ( $A_g$ ) and the dominant frequency ( $f_0$ ) of the site. Areas with low soil cohesion and soft sediment deposits tend to exhibit

higher seismic vulnerability indices, as they amplify seismic waves and prolong ground shaking. Conversely, regions with more compact and solid geological formations tend to have lower vulnerability indices due to their resistance to seismic wave amplification. Understanding the spatial variation of the seismic vulnerability index is essential for earthquake risk assessment, infrastructure resilience, and regional disaster mitigation planning.

In the NYIA region, the seismic vulnerability index ranges from 0.2 to 26, with the highest values (>19) concentrated in the alluvial plains of the Serang River (Fig. 8). This pattern aligns with geological observations, where thick accumulations of alluvial deposits (Qa) in the southern coastal region contribute to high site amplification effects. The airport environment, however, exhibits a lower seismic vulnerability

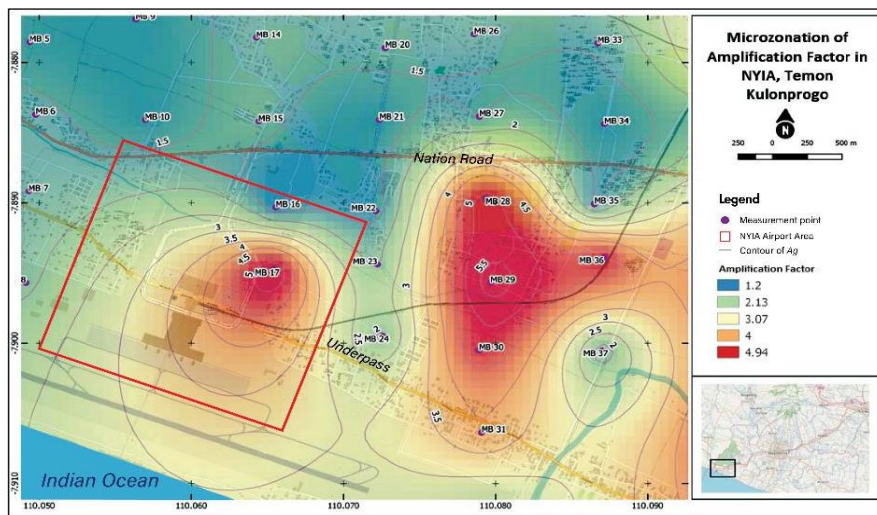


Fig.7 Microzonation of the Amplification Factor ( $A_g$ ) in the NYIA Kulonprogo Region

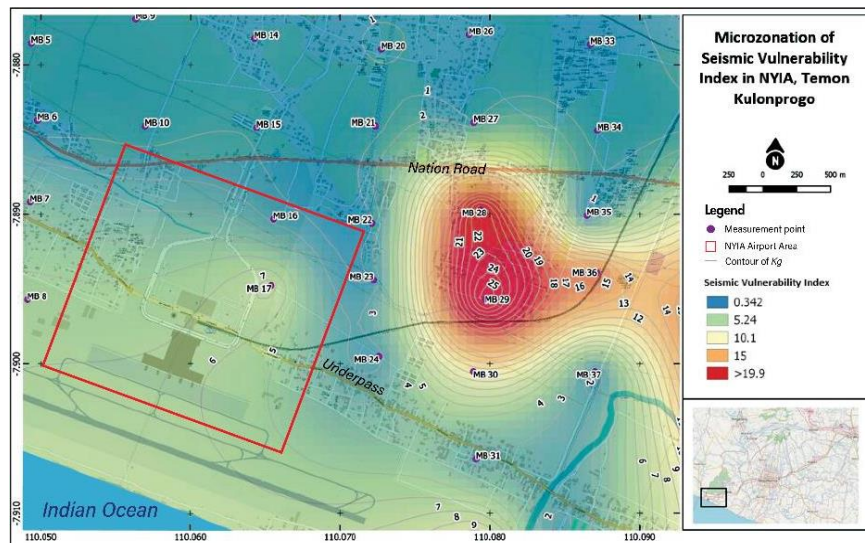


Fig.8 Microzonation of the Seismic Susceptibility Index ( $K_g$ ) in the NYIA Kulonprogo Area

index, ranging from 5 to 7, suggesting that the risk of significant site effects in this area is relatively lower compared to the alluvial plains of the Serang River. According to Nakamura (2000), regions with seismic vulnerability index values between 20 and 100 are considered high-risk zones in terms of earthquake-induced damage. Therefore, NYIA remains within the safe zone concerning earthquake impacts, although localized areas may still experience moderate site effects depending on their geological conditions.

The Spatial distribution of the seismic vulnerability index in Fig 8, reveals a distinct contrast between the eastern and western sections of the study area. The eastern part of NYIA, marked in red, exhibits high seismic vulnerability, indicating that this area is prone to significant amplification of seismic waves, likely due to the presence of unconsolidated sediments and soft alluvial deposits. In contrast, the NYIA airport site, represented in green, falls within the low vulnerability category, suggesting that the subsurface conditions provide a relatively stable foundation with minimal wave amplification effects. The interpretation of seismic vulnerability indices in this study is further supported by previous research [33], which confirms that alluvial plains and riverine deposits tend to be more susceptible to earthquake hazards due to their loose sedimentary composition. This study reinforces the importance of microzonation studies, particularly in seismically active regions, to ensure that infrastructure development aligns with geophysical risk assessments.

Moreover, the seismic vulnerability index plays a critical role in seismic hazard mitigation efforts. Areas with high seismic vulnerability require special engineering considerations, such as: reinforced foundation designs to minimize differential settlement and structural failure, soil stabilization techniques, including compaction and grouting, to enhance ground integrity, zoning regulations to restrict the construction of high-occupancy buildings in high-risk seismic zones, and implementation of seismic-resistant building materials to reduce structural damage.

#### 4.4 Microzonation of site classes in the NYIA area

The  $v_{s30}$  (shear wave velocity in the top 30 meters) is a critical parameter in seismic microzonation, providing insights into surface lithology and soil behavior under seismic loading. This parameter is widely used to classify site conditions, assess ground response to earthquakes, and evaluate liquefaction potential. A low  $v_{s30}$  value typically indicates unconsolidated sedimentary deposits, which are more prone to amplifying seismic waves, whereas a high  $v_{s30}$  value is associated with denser and more compact geological formations, offering greater resistance to seismic shaking.

In the NYIA region,  $v_{s30}$  values range from 167 m/s to 1122 m/s, reflecting variations in soil composition and geological formations (Fig. 9). Areas with  $v_{s30}$  values below 350 m/s, primarily

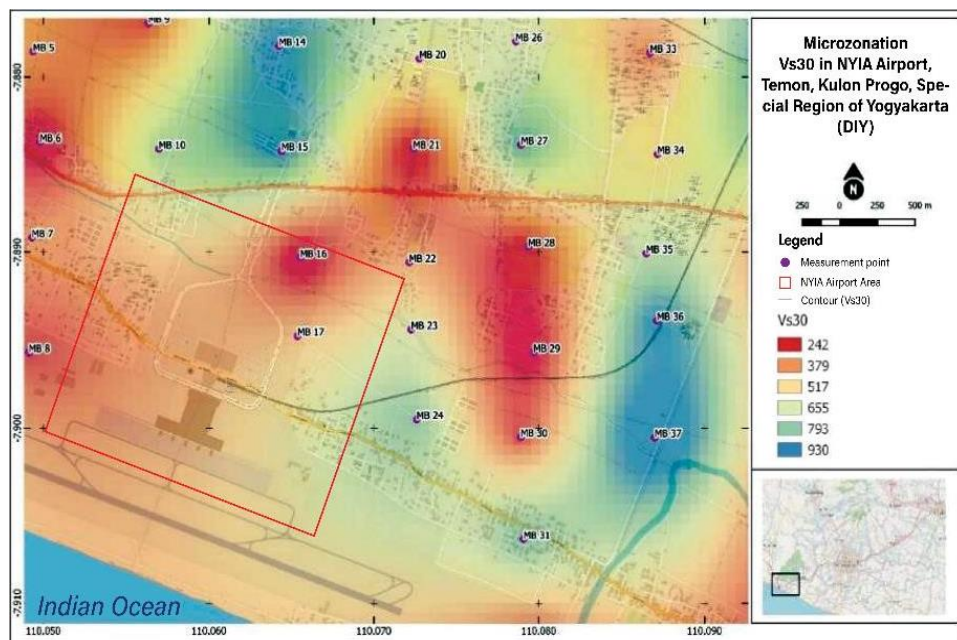


Fig.9 Microzonation of  $v_{s30}$  in the NYIA Kulonprogo Area

located in the northern and northwestern parts of the airport, are characterized by loose sedimentary materials such as cobblestone, sand, silt, and clay, which correspond to the Alluvium Formation (Qa). These deposits have lower shear wave velocities, making them more susceptible to seismic wave amplification and potential ground deformation under seismic stress. Conversely, higher  $v_{s30}$  values (>650 m/s) are found in the northern study area, particularly near the Menoreh Hills, where the Sentolo Formation (Tmps) and Kebobutak Formation (Tmok) dominate. These formations consist of denser and more compact rock materials, which exhibit higher resistance to seismic-induced deformation, making them more stable compared to alluvial deposits.

One of the key applications of  $v_{s30}$  analysis is in assessing liquefaction potential, a phenomenon where saturated, loose sediment loses its strength and behaves like a liquid during strong ground shaking, leading to significant structural damage. The NYIA airport area exhibits a moderate  $v_{s30}$  value, suggesting that liquefaction risk is relatively low. This finding is supported by Purnama et al. (2021), which concluded that areas with lower  $v_{s30}$  values are more vulnerable to liquefaction. Given that NYIA is situated on moderate to dense soil, the risk of liquefaction compromising the structural integrity of airport infrastructure is minimal.

In earthquake engineering, site classification plays a crucial role in determining ground motion amplification and structural response. According to SNI 1726:2019, the NYIA area falls into three primary site classifications: SD (Medium Soil), SC (Very Dense Soil), and SB (Rock) (Fig. 10). The Alluvium Formation (Qa), which dominates the SD and SC classifications, corresponds to regions with moderate to dense soil, whereas the SB

classification, which provides the most stable foundation for infrastructure, is associated with the Sentolo (Tmps) and Kebobutak (Tmok) formations. The dominance of SC (Very Dense Soil) in NYIA suggests that the airport is constructed on a relatively stable geological formation, minimizing excessive seismic amplification and ensuring structural integrity under earthquake loading.

The microtremor method is a widely used geophysical technique for analyzing site effects, sediment thickness, and seismic amplification potential. Through microtremor measurements, frequency and amplification values can be obtained, which provide valuable insights into the subsurface geological characteristics of a given area. The frequency value is particularly significant, as it correlates with sediment thickness—higher frequencies indicate thinner sediment layers, while lower frequencies suggest thicker sediment deposits [34;35]. This relationship is crucial in assessing seismic wave behavior, especially in regions with high seismic vulnerability.

Based on the mapping results, the northern part of the study area exhibits lower frequency values, indicating that sediment thickness is relatively greater in this region. This suggests that the northern section is dominated by unconsolidated deposits, which may have been accumulated over time due to fluvial and coastal sedimentation processes. In contrast, areas with higher frequencies, which correspond to thinner sediment layers, are found in regions where bedrock is closer to the surface. The eastern part of the study area demonstrates relatively higher seismic amplification potential, which can be linked to variations in lithology and site classification.

Previous studies have established a strong

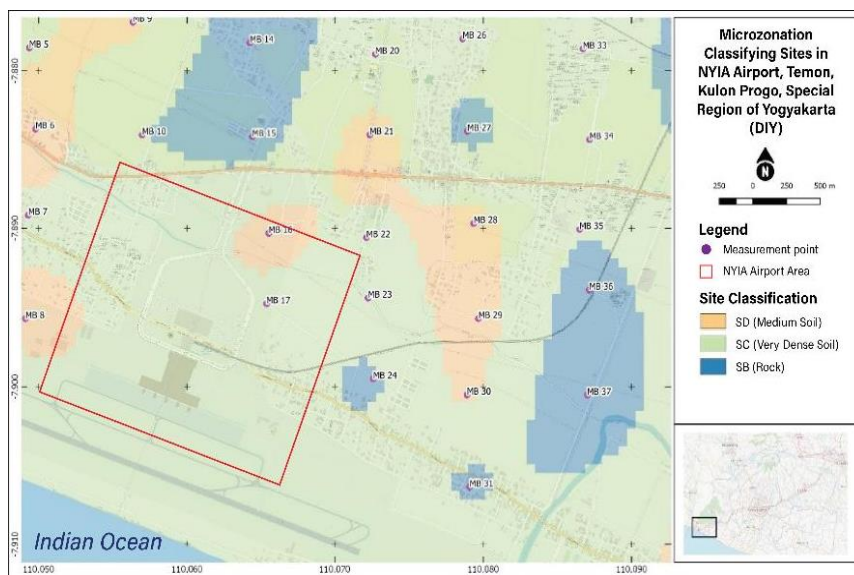


Fig 10. Site Classification Microzonation in the NYIA Kulonprogo

relationship between earthquake-induced building damage and seismic wave amplification caused by local site effects [13;14;37;36]. The amplification phenomenon primarily occurs due to impedance contrast, which refers to a significant variation in material compactness between the bedrock and overlying sedimentary layers [38; 39]. When seismic waves propagate from denser rock formations into softer sediments, their velocity decreases, and wave energy is transferred into higher amplitude motion, potentially causing structural damage in built environments.

The eastern section of the study area has been identified as having a higher potential for earthquake damage compared to other zones. This region may experience greater ground motion amplification due to the presence of thicker unconsolidated sediments, which can prolong the duration of shaking and intensify structural stress. This finding aligns with seismic microzonation principles, which emphasize the necessity of site-specific assessments to inform earthquake-resistant design. The data highlights the importance of engineering adaptation measures, such as foundation strengthening, soil improvement, and seismic isolation systems, to mitigate potential seismic hazards in this region. Understanding local site conditions through microtremor analysis contributes to better urban planning and disaster risk reduction strategies, ensuring safer infrastructure development in seismically active zones.

## 5. CONCLUSION

Based on the study conducted in the New Yogyakarta International Airport (NYIA) region, it is evident that the area is highly susceptible to seismic hazards due to its geological setting within a subduction zone between the Indo-Australian and Eurasian Plates. The alluvial deposits (Qa), composed of sand, silt, clay, and gravel, dominate the region and significantly influence local site effects, soil stability, and seismic amplification. Microtremor analysis using the Horizontal-to-Vertical Spectral Ratio (HVSr) method has revealed a wide range of dominant frequencies (0.51–10.36 Hz), where lower frequencies (<2.5 Hz) correlate with thicker sediment deposits, increasing the likelihood of seismic wave amplification and associated structural damage. Similarly, the amplification factor ( $A_g$ ) varies between 1.11 and 5.82, with higher values (>3.0) concentrated in alluvial plains, particularly in the Serang River area, indicating greater seismic vulnerability. The seismic susceptibility index ( $K_g$ ) further supports these findings, with higher values (>19) observed in unconsolidated

sedimentary regions, emphasizing the need for disaster mitigation strategies. Additionally,  $v_{s30}$  microzonation confirms that the NYIA area consists of medium to dense soils (SD, SC site classes), reducing the risk of liquefaction but still requiring careful structural planning to withstand seismic activity. These results underscore the importance of integrating microtremor analysis, geological assessments, and seismic microzonation to enhance earthquake-resistant infrastructure and minimize disaster risks in the region. Therefore, comprehensive geotechnical evaluations and engineering interventions—such as foundation strengthening, soil stabilization, and early warning systems—are essential to ensure the long-term safety and resilience of NYIA.

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