3D modeling of buried site ngempon temple, bergas, semarang regency using HVSR method

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Abstract. This study aims to model the Ngempon Temple that is still buried under the surface using the microtremor method with HVSR data processing. The measurement geometry consists of 39 points forming a rectangular grid with a measurement spacing of 2 m. The duration of data collection was 10 minutes for each point and the sampling frequency was 150 Hz. The results obtained from this study indicate the location of the temple site and subsurface 3D models of the temple site which are characterized by a frequency range of 1.28-1.32 Hz and amplification of 1.275.

1. Introduction
The Ngempon Temple complex is located in Bergas District, Semarang Regency, consisting of nine temple foundations but only four have been reconstructed, namely one main temple with a size of 3.5 mx 3.5 m with a height of 4.5 m and three ancillary temples with a size of 3 mx 3 m with a height of 4 m, there are 9 arrangements of loose stones with a size of 2.5 mx 2.5 m with a height of 60 cm and other loose stones with a size of 16 mx 1.5 m with a height of 45 cm [1].

Around the beginning of October 2018 in the north of the Ngempon Temple complex, it was found that rocks were still interconnected which was estimated to be the foundation of a temple. To find out the subsurface structure of the site, in this study geophysical measurements using the HVSR (Horizontal to Vertical Spectral Ratio) method based on the sensitivity of the soil layer and the structure contained in the soil layer as has been done by Yuliyanto et al [2]. HVSR frequency response to buried objects has a low-frequency value when the object is deeper and deeper, and vice versa if the depth of the object is shallow then the frequency value is higher.

2. Microtremor
Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented. Microtremor is a low amplitude vibration at the ground surface caused by various natural factors such as wind, sea waves, vehicle noise, and others. Microtremor has an amplitude of around 0.1-1 microns and an amplitude of 0.0001-0.01 cm / sec which can be detected using a specific seismometer [3]. The microtremor research was initially carried out by Omori in 1908, then Kanai and Tanaka in 1961 proposed the engineering of microtremor application, then in 1970, a technique using the Horizontal to Vertical spectral ratio of the microtremor was introduced by Nagoshi and Igarashi. In 1989 Nakamura began developing and introducing the Horizontal to Vertical Spectral Ratio (HVSR) technique. Microtremor which is also known as natural vibrations (ambient vibrations) originating from two main sources namely nature and humans. At low frequencies below 1 Hz, the source of the microtremor is...
natural. At high frequencies that are more than 1 Hz, the main source is human activity such as vehicle traffic, machinery and others. The location of the source is usually at ground level and varies due to day and night [4].

2.1. HVSR (Horizontal to Vertical Spectral Ratio)
The HVSR method is a method of comparing the spectrum of the horizontal component to the vertical component of the microtremor wave. Mikrotremor consists of a variety of Rayleigh wave base, it is assumed that the peak period of the H/V ratio of microtremor provides the basis of the wave period S. The H/V ratio in microtremor is the ratio of the two components that theoretically yield a value. The dominant period of a site can be approximated from a peak period of the H/V microtremor ratio. Nakamura [5] tried to separate the geological effects by normalizing the spectrum of horizontal components with vertical components at the same measuring point. The observation results show that the recording at the station located on hard rock, the maximum value of the horizontal component spectrum ratio to the vertical approaches the value of one. At the station located in soft rocks, the ratio of the maximum value to magnification (amplification), which is greater than 1. Based on these conditions, Nakamura formulated a microtremor HVSR transfer function. The effect of wave gain on the horizontal component can be expressed by Eq. (1), that is:

\[ S_E(w) = \frac{H_S(w)}{H_B(w)} \]  
(1)

with the notation, \( H_s(w) \) is the horizontal component’s microtremor spectrum on the surface and \( H_B(w) \) is the horizontal component's microtremor spectrum in the bedrock. Reinforcement of waves in vertical components can be expressed as the ratio of the vertical component spectrum on the surface and in the bedrock given by Eq. (2), ie:

\[ A_S(w) = \frac{V_S(w)}{V_B(w)} \]  
(2)

with the notation \( V_s(w) \) is the spectrum of the vertical component microtremor at the surface and \( V_B(w) \) is the spectrum of the vertical component microtremor in the bedrock. To reduce the effect of the source, the horizontal reinforcement spectrum \( S_E(w) \) is normalized to the source spectrum \( A_S(w) \) written as:

\[ S_M(w) = S_E(w) \cdot \frac{V_S(w)}{V_B(w)} \]  
(3a)

\[ \frac{S_M(w)}{A_S(w)} = \frac{[H_S(w)/V_S(w)]/[H_B(w)/V_B(w)]} \]  
(3b)

with the \( S_M(w) \) notation is the transfer function for the soil layer. If \( \frac{H_B(w)}{V_B(w)} = 1 \), then the soil transfer function will be the same as the value of the comparison of the microtremor spectrum value on the horizontal component surface with the vertical component written by:

\[ S_M(w) = H_S(w)/V_S(w) \]  
(4)

In the field observation, there are two horizontal components measured that the north-south component and the west-east component so that the Eq. (4) becomes:

\[ S_M(w) = [(H_{SN}(w)^2 + H_{WE}(w)^2)^{1/2}]/V_s \]  
(5)

with the \( H_{SN}(w) \) the notation is the microtremor spectrum of the north-south horizontal component and \( H_{WE}(w) \) is the spectrum of the east-west microtremor component.

The HVSR method is a method usually used on three-component microtremors to identify bedrock depth. This method can be used to determine the dominant resonance frequency (f0) and the peak value of HVSR (A) which can show the dynamic characteristics of the sediment. The parameters used in this method are natural amplification and frequency, both of these are related to the subsurface physical parameters to identify the geological characteristics of the study area. This method was introduced by Nakamura in 1989 using the principle of calculating the spectral ratio between the total resultant components horizontal to vertical [5]. HVSR is considered the same as the transfer function between
wave vibrations in sediments and bedrock. The amplification factor value of a place can be known from the height of the spectral peak of the HVSR curve measured by the microtremor at that place. The dominant period value or dominant frequency obtained from the HVSR curve has a correlation with the thickness level of the sedimentary layer [6].

2.2. Dominant Frequency
The dominant frequency is the frequency value that often appears so that it is referred to as the frequency value of the rock layers in the region so that the frequency value can indicate the type and characteristics of the rock. The natural frequency value of an area is influenced by the thickness of the weathered layer and the average velocity of the subsurface. Lancet and Brad [7] have conducted a simulation test using six simple geological structure models with a combination of shear wave velocity contrast variations and soil layer thickness. Simulation results show the peak value of the frequency changes with variations in geological conditions.

2.3. Amplification
Amplification is an enlargement of seismic waves that occur due to significant differences between layers, in other words, seismic waves will experience magnification if it propagates in one medium to another medium which is softer than the initial medium in its path. The greater the difference, the magnification experienced by the wave will be even greater. The amplification factor value of the soil is related to the contrast ratio of the surface layer impedance with the underlying layer [8]. If the contrast impedance ratio of the two layers is high, the reinforcement factor value is also high, and vice versa. Amplification is directly proportional to the value of the horizontal and vertical spectrum (H / V) ratio. Amplification value can increase if the rock has been deformed (weathering, folding or enlarged) 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 in the rock body.

3. Data processing
Measurements were made by forming a rectangular grid consisting of 39 points with a measurement spacing of 2 m. The duration of data collection was 10 minutes for each point and the sampling frequency was 150 Hz. The results of data collection in the form of position data and microtremor signals in a time function consisting of two horizontal components (component X (EW) and component Y (NS) and one vertical component which are then processed into dominant frequency data using Fast Fourier Transform (FFT) from the Geopsy software to obtain the HVSR spectrum curve. The output value in the form of frequency and amplification values is used as input to create an interface with Voxler-4 software.

4. Result and discussion
Based on the frequency value, the study area has a frequency range value of 0.11-0.43 Hz and amplification in the range of 0.15-2.72. The location of the buried temple site is at the measurement coordinates of 11.4-16.2 meters on the x-axis and 0.4-3.0 meters on the y-axis and is located at a frequency of 1.28-1.32 Hz (Figure 1 and Table 1).
Figure 1. 2D modeling used to delineate the location of the hidden Ngempon Temple site. The alleged location of the temple is in the box segment at the bottom with a light blue background with a frequency of 1.28-1.32 Hz.

Table 1  Calculated frequencies and amplification values

| Points | X  | Y  | Freq (Hz) | A   |
|--------|----|----|-----------|-----|
| A9     | 9  | 6  | 0.326832  | 2.49511|
| A11    | 11 | 6  | 0.197239  | 1.41818|
| A13    | 13 | 6  | 0.158644  | 1.56135|
| A15    | 15 | 6  | 0.176888  | 1.44379|
| A17    | 17 | 6  | 0.200158  | 1.41915|
| A19    | 19 | 6  | 0.149052  | 1.41359|
| B1     | 1  | 4  | 0.415570  | 1.62892|
| B3     | 3  | 4  | 0.158331  | 1.15156|
| B5     | 5  | 4  | 0.150181  | 1.33286|
| B7     | 7  | 4  | 0.105487  | 1.58010|
| B9     | 9  | 4  | 0.160445  | 1.20002|
| B11    | 11 | 4  | 0.152088  | 1.00001|
| B13    | 13 | 4  | 0.156409  | 1.40493|
| B15    | 15 | 4  | 0.246549  | 1.73437|
| B17    | 17 | 4  | 0.149525  | 1.16407|
| B19    | 19 | 4  | 0.322565  | 1.41166|
| B21    | 21 | 4  | 0.388489  | 1.65347|
| C1     | 1  | 2  | 0.174291  | 1.46525|
| C3     | 3  | 2  | 0.134145  | 1.10361|
| C5     | 5  | 2  | 0.153891  | 1.45727|
| C7     | 7  | 2  | 0.189551  | 0.15189|
| C9     | 9  | 2  | 0.428071  | 1.58235|
| C11    | 11 | 2  | 0.161869  | 1.70166|
| C13    | 13 | 2  | 0.128173  | 1.82221|
| C15    | 15 | 2  | 0.128179  | 1.82207|
| C17    | 17 | 2  | 0.131140  | 1.12633|
| C19    | 19 | 2  | 0.138048  | 1.52275|
| C21    | 21 | 2  | 0.141888  | 2.71958|
| D1     | 1  | 0  | 0.283737  | 1.33538|
| D3     | 3  | 0  | 0.134463  | 1.04798|
| D5     | 5  | 0  | 0.239841  | 1.37401|
| D7     | 7  | 0  | 0.136895  | 1.79467|
| D9     | 9  | 0  | 0.143863  | 2.07287|
| D11    | 11 | 0  | 0.156216  | 1.52125|
| D13    | 13 | 0  | 0.162666  | 1.33055|
| D15    | 15 | 0  | 0.218780  | 1.72479|
| D17    | 17 | 0  | 0.130266  | 1.48758|
| D19    | 19 | 0  | 0.130266  | 1.48758|
| D21    | 21 | 0  | 0.143863  | 2.07287|
The existence of the temple was also identified based on 3D modeling for isosurface amplification values of 1.275 in the 2-6 Hz frequency range.

![3D modeling](image)

**Figure 2.** 3D modeling for an amplification value of 1.275 with a frequency range of 2-6 Hz (a) side view, (b) bottom view.

5. Conclusion

Based on 3D modeling the location of the temple site and subsurface models can clearly be characterized by a frequency range of 1.28-1.32 Hz and amplification of 1.275.

Acknowledgments

The authors wish to extend their gratitude to Diponegoro University for the funding allocated for this research via Hibah Fundamental DRPM Dikti 2019

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